CROSS-COUPLING EFFECTS OF INTERCONNECTED DC-DC CONVERTER SYSTEM IN PV APPLICATIONS

Joy Narayan Das

Department of Electrical Engineering
National Institute of Technology Rourkela

CROSS-COUPLING EFFECTS OF INTERCONNECTED DC-DC CONVERTER SYSTEM IN PV APPLICATIONS

Thesis submitted in the partial fulfilment

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by

Joy Narayan Das

ROLL-214EE5373

Under the guidance of

Prof. Somnath Maity

Department of Electrical Engineering

National Institute of Technology, Rourkela

Department of Electrical Engineering
National Institute of Technology Rourkela

May 27, 2016

Certificate of Examination

This is to certify that the **dissertation report/thesis** entitled "***Cross-coupling Effects of Interconnected DC-DC Converter System in PV Applications***", submitted to the National Institute of Technology, Rourkela by ***Joy Narayan Das, ROLL-214EE5373*** of Industrial Electronics Specialization for the award of **Master of Technology** in **Electrical Engineering**, is a bonafide work of research carried out by him under my supervision and guidance.

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X

Date: Dr. Somnath Maity

Place: Dept. of Electrical Engg.

Declaration of Originality

I, *JOY NARAYAN DAS*, Roll Number 214EE5373, hereby declare that this thesis entitled "***Cross-coupling Effects of Interconnected DC-DC Converter System in PV Applications"*** presents my original work carried out as a Master degree student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Reference" or "Bibliography".

I have also submitted my original research records to the scrutiny committee for evaluation of my thesis.

May 27, 2016 JOY NARAYAN DAS

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NIT Rourkela ROLL-214EE5373

ABSTRACT

Due to increase in global warming, the world is renewing its focus on renewable sources of energy. Among them, Photovoltaic (PV) generation has attracted vast interests worldwide. In PV generation, solar photovoltaic panels absorb solar radiation to generate power through photovoltaic effect. However, the PV systems are found to be vulnerable to mismatch conditions and other atmospheric conditions. So, to extract maximum power under partial shading condition and module mismatching, calls for new innovation methods and technologies.

In this thesis, the modelling of a PV module is discussed. The characteristics of photo-voltaic module are observed for various solar irradiation and different atmospheric condition. The PV panel is operated at its maximum power point by using P & O method and the duty cycle control is being employed to get the peak power. The photovoltaic modules are connected in series to get the high voltage of system. The classical MPPT control method does not work when the photo-voltaic modules are connected in series, under extreme conditions and under partial shading. Thus, Distributed Maximum power point tracking (DMPPT) control method is used to extract power under such conditions. However, due to cascading of dc-dc converters, there is a surprise element of cross-coupling effects. The coupling effects are the disturbances which are present in the system because of cascading of dc-dc converters. Cross-coupling effects are studied in this thesis.

***Keywords*: DMPPT; Series configuration; Parallel Configuration; Cross-coupling**

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Introduction

CHAPTER 1

1.1 Introduction:

The utility of PV systems has changed from single standalone systems to large grid connected systems. Several factors have led to the worldwide use of photovoltaic systems. Global warming, increased need for more power generation, providing clean and sustainable energy resource have led to the increase in use of photovoltaic systems. In PV system design, PV panels are usually stacked in series to increase the voltage for grid connection with central inverter. However, the PV systems are found to be vulnerable to shading effects and other atmospheric conditions. This is because the functioning of real PV grids involves mismatch conditions which are more frequent and expected. The P-V characteristics of string of PV panels are greatly influenced by mismatch conditions. The energy output of the mismatched PV strings can fall even down to 20-30% in comparison to matched strings [1]. This calls for new methodologies and technologies to extract maximum power under shading effects, module mismatching and other dynamic atmospheric conditions. Here, distributed maximum power point tracking (DMPPT) method is employed, where each PV module is connected to individual dc-dc converter so as to extract maximum power under extreme conditions. DMPPT has advantage over ordinary MPPT. Because in standard ordinary MPPT, there are more than one peak characteristic due to failure of MPPT tracking under mismatch conditions, thus resulting in persistent fall of the grid power and system efficiency. So, DMPPT technique is used to extract maximum power under these conditions. There are two ways to use DMPPT system-Series DMPPT and Parallel DMPPT, depending on the type of connection of converter output terminals. However, the performance of solar PV modules is affected by the sudden change in the irradiation levels affecting the performance of their respective dc-dc converters. Thus, their respective converters change their duty cycle in respect to their respective power output goal. However, due to cascading of dc-dc converters, there is a surprise element of cross-coupling effects. For parallel configuration, the effects of cross-coupling are not present unless there are some non-idealities are injected to the system. However, in series configuration, the operation of other dc-dc converters is affected by the sudden change in irradiation. These disturbances are known as cross-coupling effects. However, to eliminate the cross-coupling effects in series configuration, we need to apply input voltage feedback control. In this thesis, the effects of cross-coupling are being studied and the concept of reducing cross-coupling effects is to be studied in future.

1.2 Literature Review

A number of literatures are being studied to analyse the cross-coupling effects of interconnected converters on Photovoltaic system. The modelling of PV array is being studied and simulated. It gives the characteristics of PV modelling and the PV module under various atmospheric conditions. J.Huusari, T.Suntio offers the study on characteristic modelling study of Photovoltaic modules under various atmospheric conditions [8]. Geoffrey R. Walker gives the modelling of dc-dc converters with which it can perform the system more efficiently [4]. We have studied different maximum power techniques for the system as shown in N. Femia, G. Petrone [1]. The effect of cross-coupling due to series and parallel connection is shown Petrone, Carlos [9].

1.3 Thesis Objectives

- Modelling of photovoltaic module and to note its characteristics.
- Study different dc-dc converter Topologies
- Study the design and performance of MPPT methods
- Study the behaviour and need of DMPPT technique
- Study the effect of cross-coupling on the system
- Implement and study the Perturb and Observe algorithm in PV application

CHAPTER **2**

Photovoltaic Module Modelling

Chapter-2
Photovoltaic Module Modelling

2.1 Introduction

Solar photovoltaic panels absorb solar radiation to generate power through photovoltaic effect. Photovoltaic modules consist of several Photo-Voltaic cells connected either in series or parallel so as to increase the voltage, current and improve the system performance. It is because the voltage level of individual PV cell is very less in compared to grid, thus PV cells are stacked to improve the system voltage. PV array is the total power generating system consisting of PV modules and panels.

Here, the model of PV module is introduced so as to analyse working of photovoltaic power system. It is based in relation to working of photovoltaic cell one diode model.

2.2 Ideal PV cell one diode model

The model of ideal single PV cell gives the relation between the characteristics of current I and voltage V of a photovoltaic cell. Here, we do not consider the internal losses of the model which may occur due to current. Here, the diode is connected in anti-parallel to the current source.

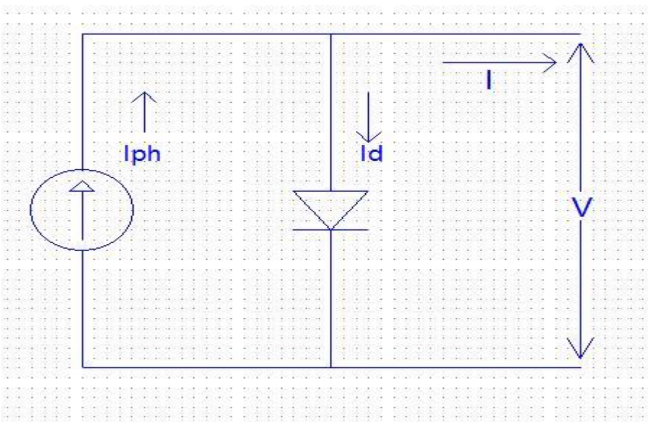

Figure-1**- Ideal PV cell one diode model**

Here, Iph = light generated photocurrent.

Id= diode current.

I= output current.

V= diode voltage.

The output model current I is calculated as:-

$$I = Iph - Id \tag{2.1}$$

The diode current Id is directly linked to the dark saturation current Io. It is given by:-

$$Id = Io[\exp(\frac{V}{AN_S V_T}) - 1] \tag{2.2}$$

Where, Io= dark saturation current.

A= Ideality factor.

Ns= the no. of PV cells connected in series.

V_T= PV cell thermal voltage.

The thermal voltage of PV module is dependent on the temperature of the module. It is given by:-

$$V_T = \frac{kN_S T_C}{q} \tag{2.3}$$

Where, k= Boltzmann constant= 1.381 x 10-23 J/K.

Tc= temperature of PV cell.

q= electron charge (1.6 x 10-19 C)

VTc = 26 mV at 300 K for silicon cell

Practically, we cannot ignore losses because of series resistance (Rs) and parallel resistance (Rp) due to their presence in practical model.

2.2.1 Practical PV model with series resistance (Rs):-

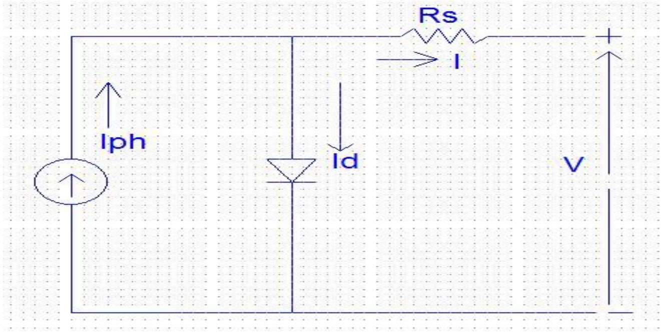

Figure 2- Practical PV model with *Rs*

Taking Rs into consideration, the diode current is written as:-

$$I_d = I_o[\exp(\frac{V + IR_S}{AN_S V_T}) - 1] \tag{2.4}$$

And output current is given by:-

$$I = Iph - Id \tag{2.5}$$

2.2.2 Practical PV model with series resistance (Rs) and parallel resistance (Rp):-

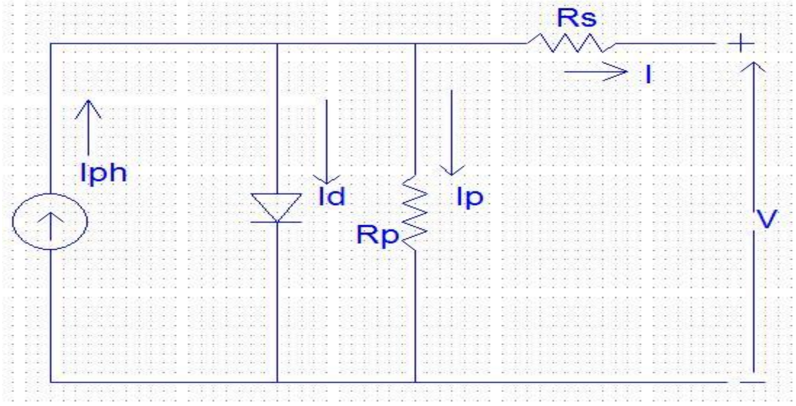

Figure 3- Practical PV model with *Rs* and *Rp*

The output current of PV module is given by:-

$$I = Iph - Id - Ip \tag{2.6}$$

Where,

Ip = current through the parallel resistor.

$$I = Iph - Io[\exp(\frac{V + IRs}{ANsV_T}) - 1] - \frac{V + IRs}{Rp} \quad (2.7)$$

2.3 Bypass diodes Operation

The bypass diodes are used in photovoltaic module for protection of photovoltaic cells due to hot spots by considering diode parallel resistance *R*p to be very high and photo-generated current *I*ph to be nil.

The bypass diodes affect the I–*V* characteristic of photovoltaic module due to partial shading by comparing entire photovoltaic module current with the shaded cells short circuit current. for voltage below reference voltage, the entire photovoltaic module current is more than shaded short circuit current and the entire module voltage is the combination of non-shaded photovoltaic cells voltage and the bypass diode voltage which is conducting and is anti-parallel with respect to shaded photovoltaic cell. For voltage more than reference voltage, photovoltaic module current is less than shaded cell short circuit current, and so there is no current flow due to bypass diode. Thus, here in this example, the PV module voltage is combination of non-shaded cell voltage and shaded cell voltage.

2.4 PV Parameter determination

2.4.1 Value of Iph derivation:

The photo-generated current (Iph) can be derived in any circumstances with relation to current due to short-circuit by considering that in short-circuit situation the diode current is very less and almost all of photocurrent flows through the terminals of model.

The photocurrent can be obtained as:-

$$Iph = (Isc,_{STC} + k_i \Delta T) \frac{G}{G_{STC}} \frac{Rp + Rs}{Rp} \quad (2.8)$$

Where, Isc,STC = short circuit current in standard test conditions (STC).

Ki= temperature coefficient at STC.

G= illumination on photovoltaic surface.

ΔT=T-TSTC

Where, T= temperature of PV module.

In standard test conditions, the photo-generated illumination distributions are AM1.5, photovoltaic temperature TSTC is 25 ◦C, and the illumination GSTC is 1000 W/m^2.

2.4.2 Value of Io Derivation:-

The dark saturation current Io can be obtained by solving equation (2.7) in open-circuit condition. It depends on the temperature and structure of photovoltaic cell. When the temperature effect is taken into consideration and assuming open circuit voltage, the dark saturation current Io is obtained as:-

$$Io = \frac{Iph - (V_{OC,\,STC} + k_u \Delta T) / Rp}{\exp((Voc,_{STC} + k_u \Delta T) / AV_T) - 1} \tag{2.9}$$

Where, Voc,STC = open circuit voltage in STC

Ku = temperature coefficient of open circuit voltage.

The photovoltaic module temperature depends linearly on solar irradiance. It is given by:-

$$T = Tamb + k_t G \tag{2.10}$$

Where, Tamb= ambient temperature.

Kt= temperature coefficient, which is obtained by using the nominal operating cell temperature (NOCT) of the photovoltaic cell. Nominal operating cell temperature of PV cell refers to the atmospheric conditions where solar irradiance is 800 W/m^2, and ambient temperature=20 ◦C.

2.4.3 Value of Rp and Rs Derivation:-

The series resistance and the shunt resistance of photovoltaic module is obtained by using the open circuit voltage, the short circuit current, and the MPP characteristics of the photovoltaic module. The value of Rs and Rp is chosen such that MPP due to photovoltaic module matches with PV module MPP due to STC. It is derived using:-

$$P_{MPP,STC} = V_{MPP,STC}\{I_{Ph,STC} - Io[\exp(\frac{V_{MPP,STC} + R_S \cdot I_{MPP,STC}}{AV_{T,STC}}) - 1] - \frac{V_{MPP,STC} + Rs \cdot I_{MPP,STC}}{Rp}\}$$

(2.11)

Where, PMPP,STC = power,

VMPP,STC= voltage,

IMPP,STC= Photo-Voltaic current at MPP due to STC.

The photo current in standard test conditions $I_{Ph,STC}$ derived using ΔT = 0K and G = GSTC. The shunt resistance Rp can be derived from equation (2.11) in relation to series resistance Rs. It is given as:-

$$R_{P=} \frac{V^2_{MPP,STC} + V_{MPP,STC}.I_{MPP,STC}.R_S}{V_{MPP,STC}.I_{Ph,STC} - V_{MPP,STC}.I_{O,STC}\left[exp\left(\frac{V_{MPP,STC} + I_{MPP,STC}.R_S}{AV_{T,STC}}\right) - 1\right] - P_{MPP,STC}}$$

(2.12)

Thus, the photovoltaic characteristic is used to calculate and match with the Open Circuit characteristics, Short Circuit characteristics, and Maximum Power Point characteristics on I–V photovoltaic characteristics at STC.

2.5 MATLAB SIMULATION:-

A- PV MODULE

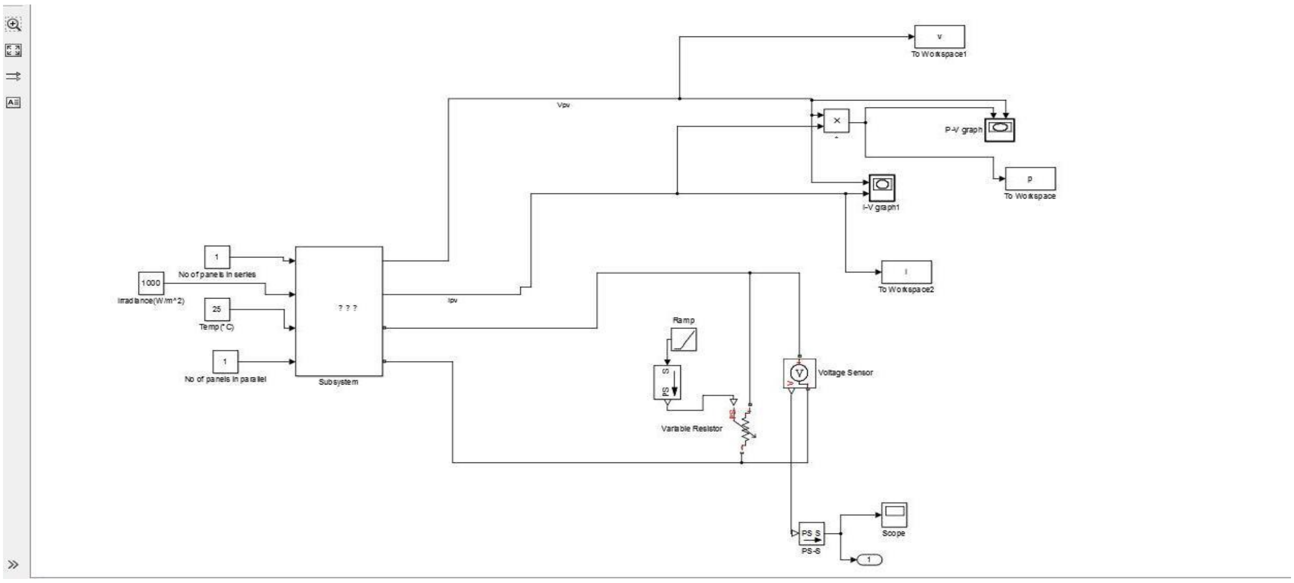

Figure 4-PVmodule simulation

B-PV MODULE SUBSYSTEM

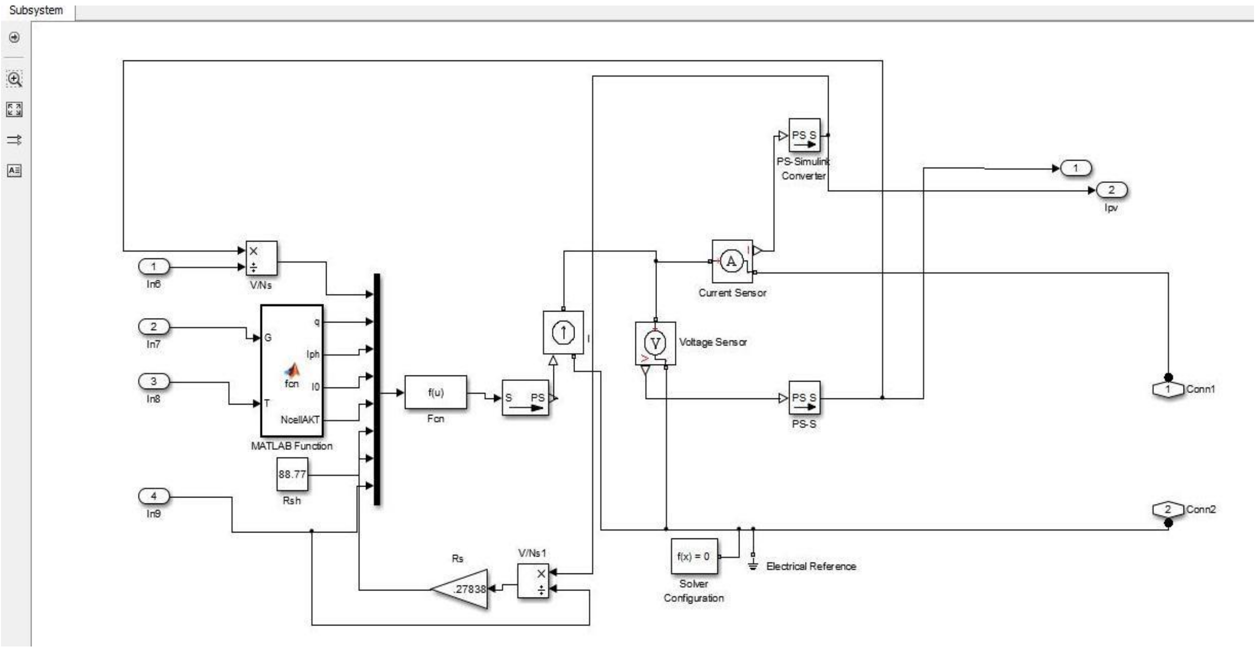

Figure 5-PV module subsystem

2.6 RESULTS:-

A. PV MODULE

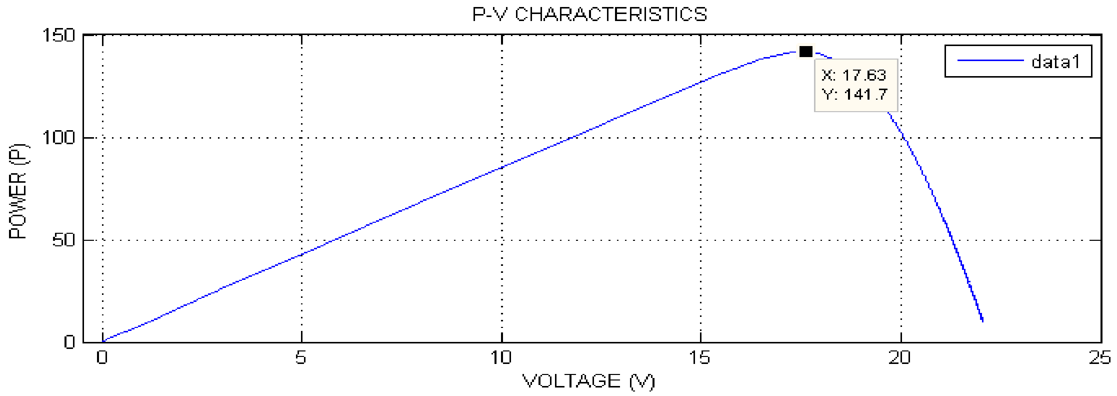

Figure 6- P vs V CHARACTERISTICS

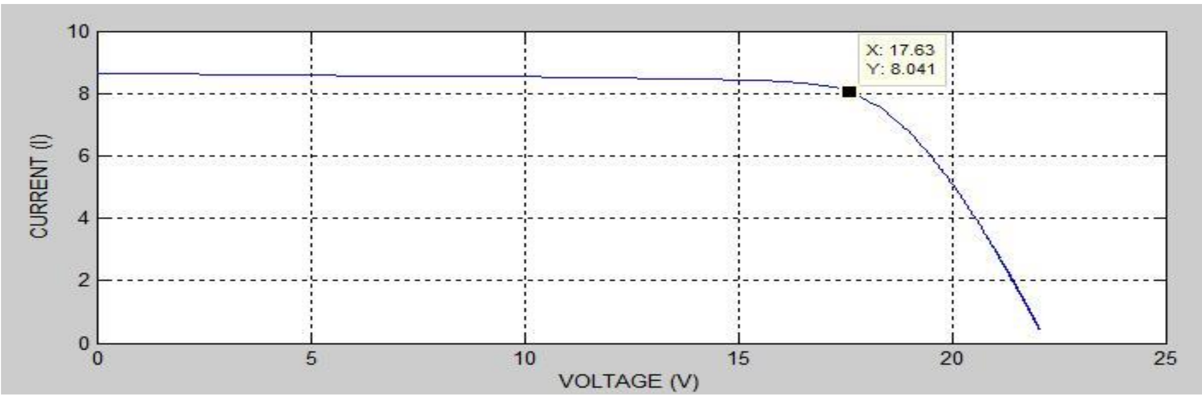

Figure 7- I vs V CHARACTERISTICS

PARAMETERS

Parameters	**Values**
Pmp (W)	141.7
Imp (A)	8.041
Vmp (V)	17.63
Isc ,ref(A)	8.66
Voc ,ref(V)	22.25
Rp (Ω)	88.77
Rs (Ω)	0.27838
Ki	0.0023822
Temp (°C)	25
A	0.95576
Irradiance(w/m^2)	1000
N cells	36

B. BY VARYING IRRADIANCE

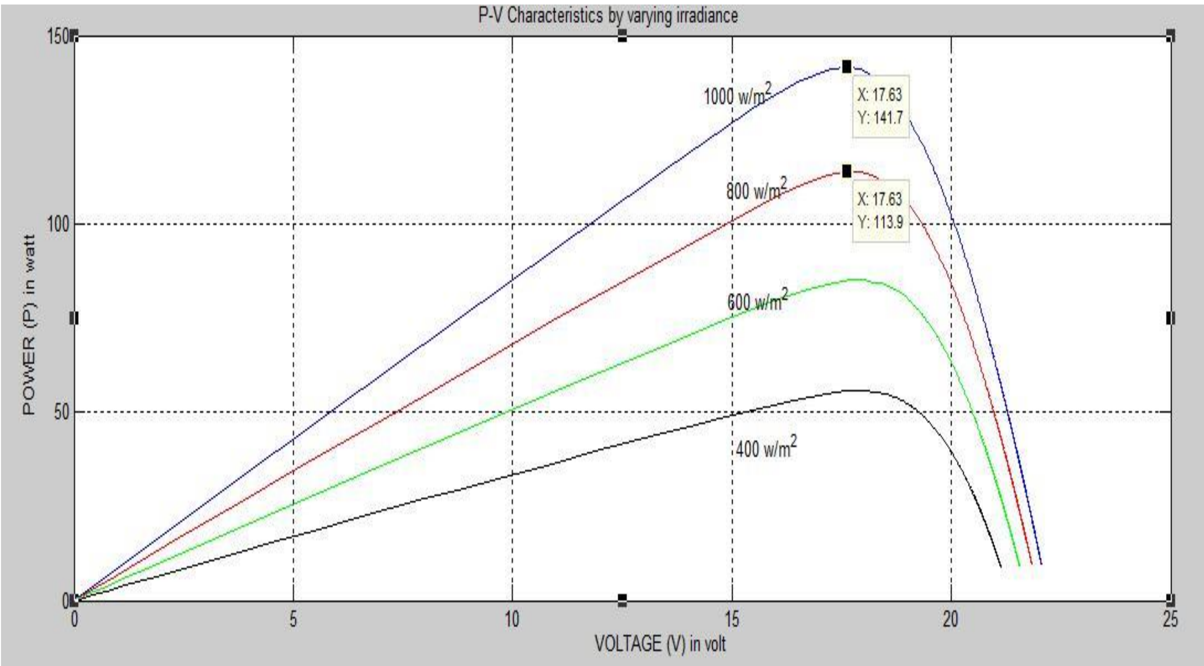

Figure 8- P vs V CHARACTERISTICS BY VARYING IRRADIANCE

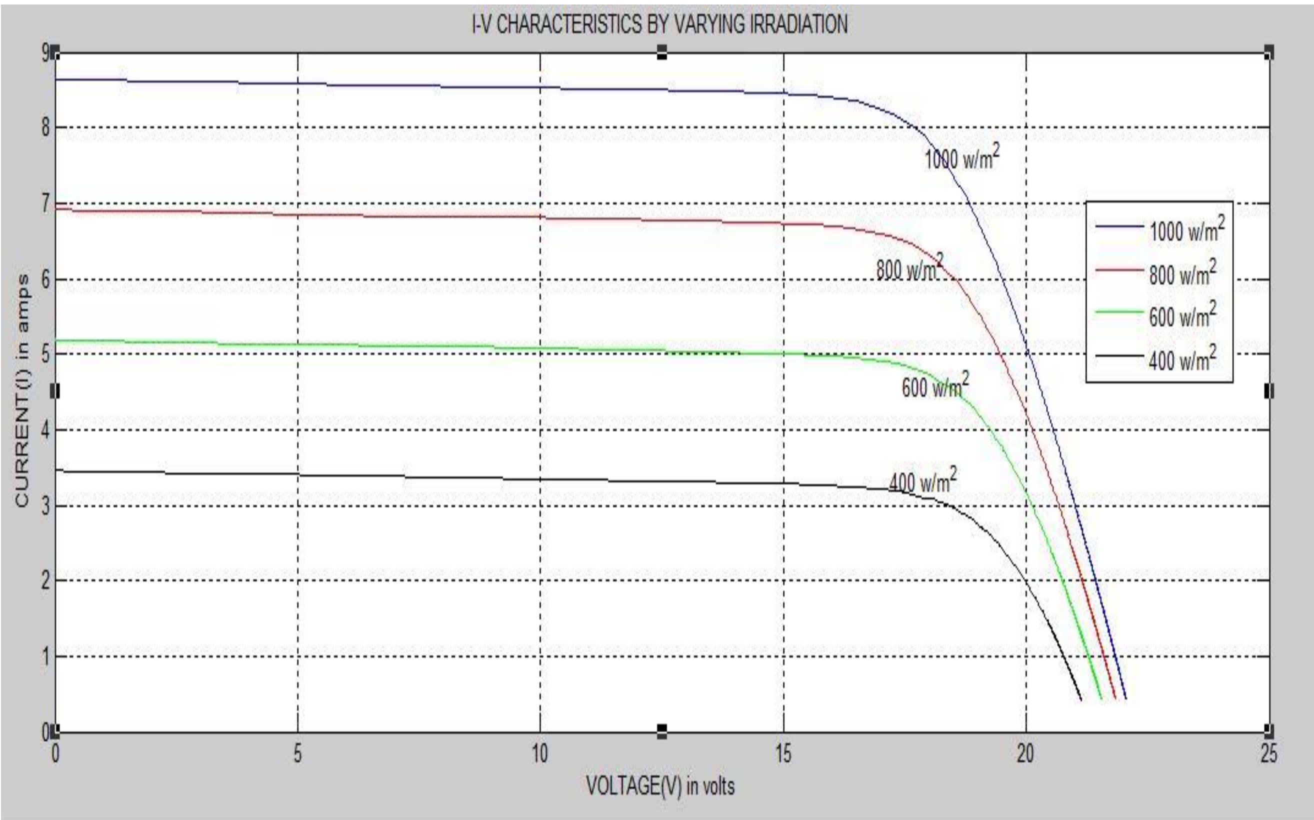

Figure 9- I vs V CHARACTERISTICS BY VARYING IRRADIANCE

C. **BY VARYING TEMPERATURE**

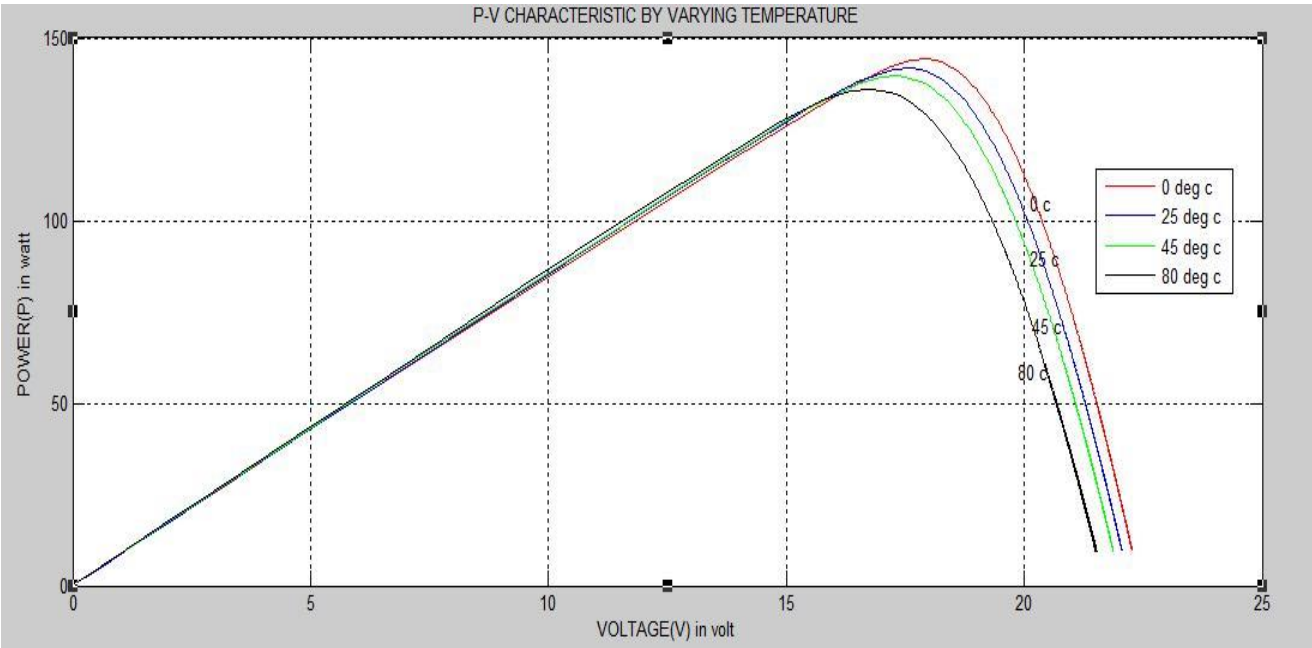

Figure 10- P vs V CHARACTERISTICS BY VARYING TEMPERATURE

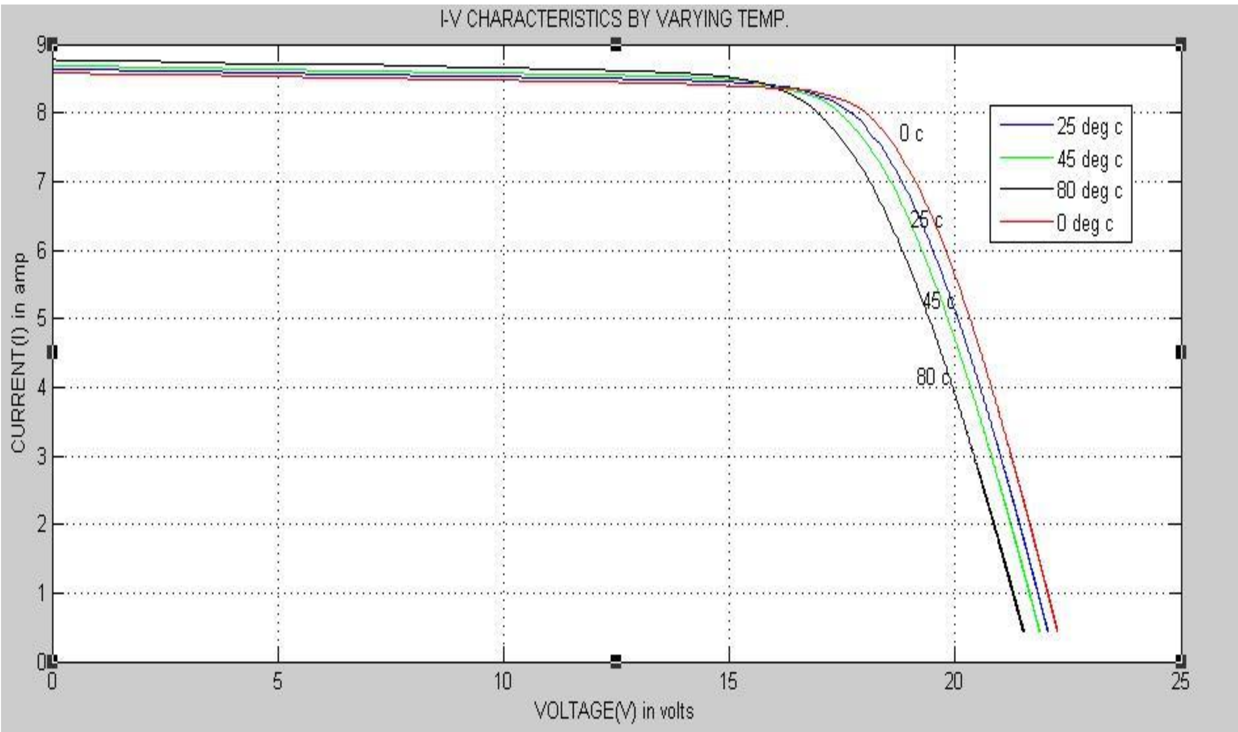

Figure 11- I vs V CHARACTERISTICS BY VARYING TEMPERATURE

2.7 CONCLUSION

a) **CHARACTERISTICS OF PV MODULE DUE TO VARYING IRRADIATION**

- Current changes directly as it are proportional to the level of irradiance. Thus, there is increase of current due to higher irradiation level.
- The output voltage increases also according to irradiation level and the irradiation level also increases the power output at constant temperature.
- It is also noted that accuracy of module decreases because of decrease in irradiation level.

b) **CHARACTERISTIC OF PV MODULE DUE TO VARYING TEMPERATURE**

- With increase in temperature, there is decrease in voltage, thus resulting in decrease of power.
- There is approximately very little change in current due to temperature change.
- Thus, there is very little change in constant current region due to change in temperature however, there is drop in voltage due to increase of temperature.

CHAPTER 3

DC-DC Converter Topologies

Chapter-3

DC-DC CONVERTER TOPOLOGIES

The dc-dc converters are connected between load and photovoltaic array so as to control the power output and voltage of the system and improve the performance. The power across the load will be less than the maximum power if the load is connected directly to photovoltaic modules for varying atmospheric conditions on I-V non linear characteristic of photovoltaic array. The dc-dc converter is connected between the photovoltaic module and load so as to operate the photovoltaic module for varying atmospheric conditions, temperatures and irradiations around peak power point. The voltage of the photovoltaic system is increased or decreased by converter operation taking the requirements of system and load.

The dc-dc converters used are given as:-

1. Buck converter
2. Boost converter
3. Buck Boost converter

3.1 Buck converter

The buck converter step downs or decreases the voltage output of the converter. It is also called as step-down converter. The operation of buck converter is carried out in two modes.

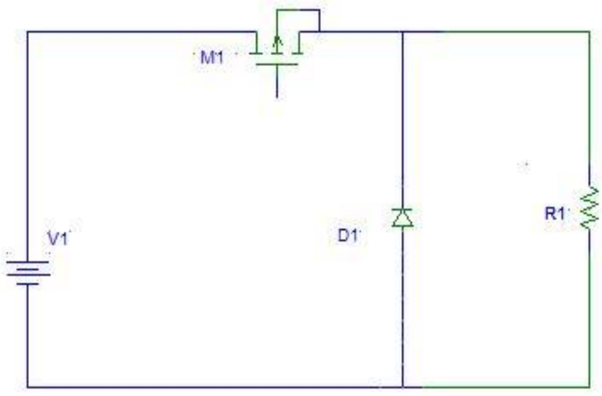

Figure 12- BUCK CONVERTER

In mode 1, switch S1 is switched on for time interval T1, and the voltage across the load is input voltage Vin. In mode 2, when switch S1 is switched off for time interval T2 and the voltage is found to be zero across load. Output voltage that is found across load and its waveform is shown in (fig 14) as:-

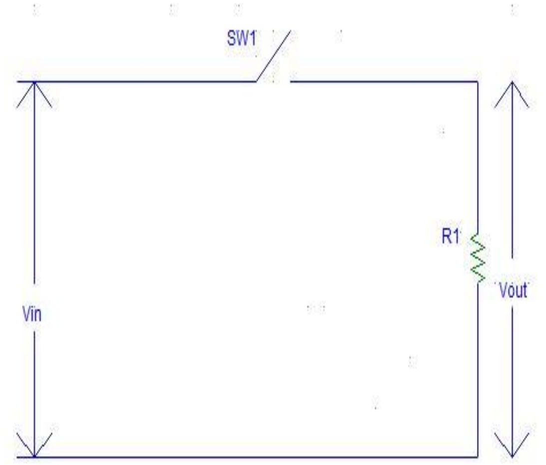

Figure 13-BUCK CONVERTER

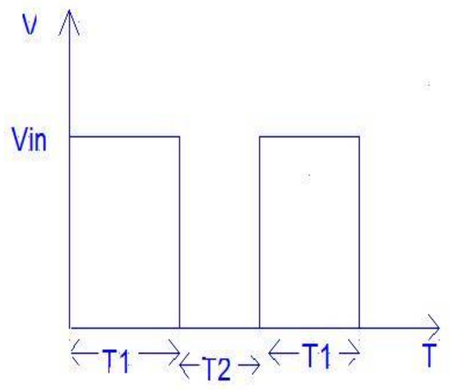

Figure 14-OUTPUT VOLTAGE WAVEFORM

The average load output voltage is:-

$$V_{avg,o} = \frac{1}{T}\int_0^{T_1} V_{out}\,.\partial t = \frac{T_1}{T}.V_{in} = fT_1V_{in} = DV_{in} \quad (3.1)$$

The average load output current is:-

$$Iavg,o = \frac{V_{avg,o}}{R} = \frac{D.V_{in}}{R} \quad (3.2)$$

Where, T= chopping time interval T

$D = \frac{T_1}{T}$ =Duty ratio

f= chopping frequency

Output rms voltage is given by:-

$$V_{rms,o} = \frac{1}{T}\int_0^{DT} Vout^2.\partial t = \sqrt{D}.V_{in} \tag{3.3}$$

Continuous mode of Buck Converter with Resistive Load and Filter

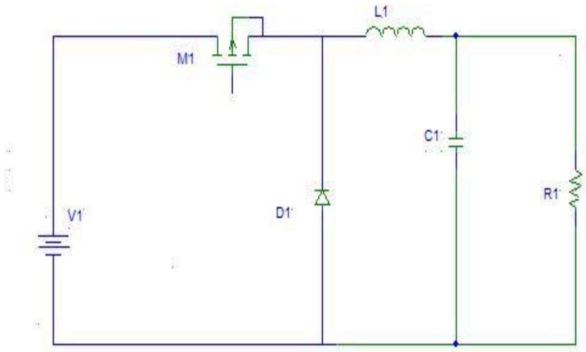

Figure 15- Buck converter with resistive load and filter

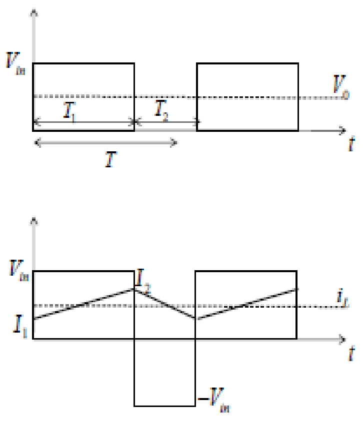

Figure 16- Voltage and current waveform

The converter has presence of harmonics in output voltage and current because of switching action of the converter. So as to filter out the harmonics, converter circuit consists of LC filters. The converter having LC filter to filter the harmonics is shown in Figure 16 .The two modes of operation of the converter are explained as:-

In mode 1, the inductor voltage drop is given by:-

$$e_{Lf} = V_{in} - V_o = L_f . \frac{di_L}{dt} = L_f . \frac{di_{SW}}{dt} \tag{3.4}$$

Where, i_L = inductor current

i_{SW} = switch current

When the converter switching frequency is high, the current i_L is considered to be changing linearly. Thus equation (3.4) can be rewritten as

$$e_{Lf} = V_{in} - V_o = L_f . \frac{\Delta i_L}{T_{on}} = L_f . \frac{di_L}{Dt} \tag{3.5}$$

Where, T_{on} = switch on interval

T= switching time period

3.2 Boost converter

Boost converter is step up converter. It increases the voltage output of the converter than that of the input. It consists of a diode and a switch and filters LC. The capacitive filter adds to the converter output voltage to reduce distortions present in the output voltage. The impedance of boost converter is less than the load impedance so that the voltage does not reach near the open circuit voltage of photovoltaic module. The operation of the boost converter take place in two modes:- In mode 1, switch S1 is switched on for time interval T1, and the current flows through capacitor C, inductor L and switch . In mode 2, when switch S1 is switched off for time interval T2, the current flows through load, inductor L, diode and capacitor C. The current across input is continuous and the efficiency is more in the system load. The system output voltage change according to the duty cycle. Boost converters are used when the array voltage is less than the required system voltage.

The voltage across output is given as:-

$$Vout = \frac{1}{1-D} * Vin \tag{3.6}$$

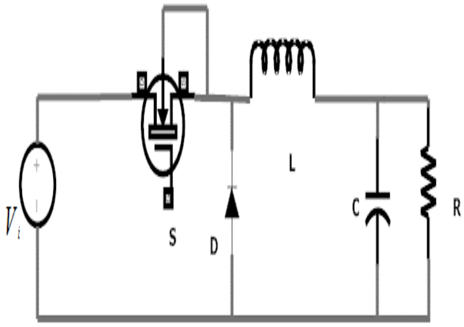

Figure 17-BOOST CONVERTER

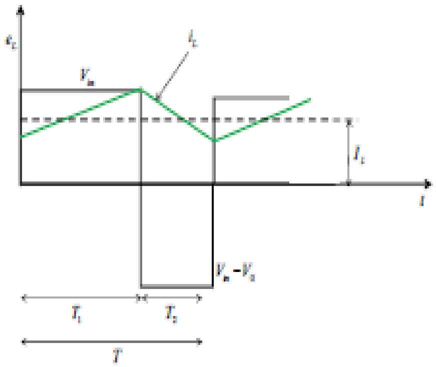

Figure 18- Inductor current waveform

The boost converter operation is carried out considering two modes. In mode 1, switch S1 is switched on for time interval T1, the current across the inductor increases and thus the inductor energy also increases. When switch S1 is switched off for time interval T2, the inductor energy also flows through diode D1, load and current across inductor also decreases.

If switch S1 is switched on, the inductor voltage is given as

$$v_L = L\frac{di}{dt} \tag{3.7}$$

The inductor current ripple (peak -peak) is given as

$$\Delta I = \frac{V_S}{L} * T_1 \tag{3.8}$$

The average load output voltage given as

$$V_O = V_S + L\frac{\Delta I}{T_2} = V_S\left(1 + \frac{T_1}{T_2}\right) = V_S\frac{1}{1-D} \tag{3.9}$$

It is noticed from equation 3.4 that load voltage is increased by changing D. When D=0, the voltage across output is minimum and found to be Vs. When D=1, the converter cannot be switched on continuously and for values of D nearing unity, the voltage output changes according to D. The output voltage vs duty ratio is given by:-

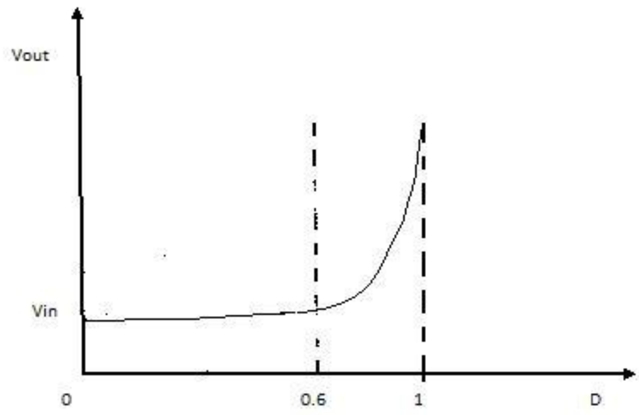

Figure 19-Boost Converter- Output voltage vs. Duty ratio

The operation of Boost Converter with Resistive load and Filter is shown in figure 3d.

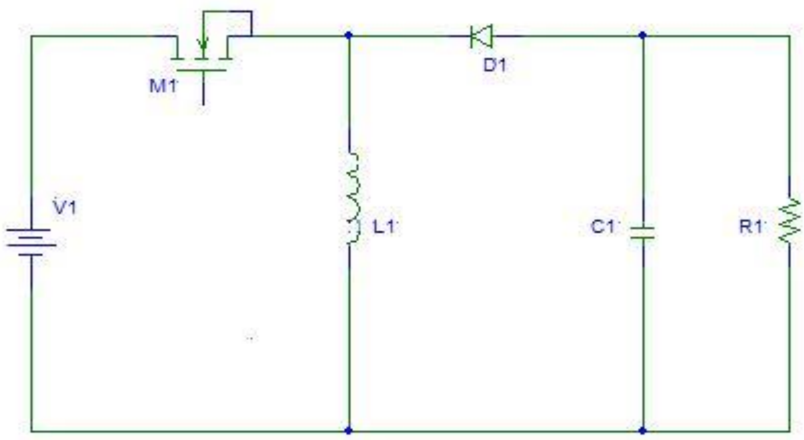

Figure 20-BOOST CONVERTER with filter

Considering the current across inductor increases linearly in time duration T1 from I_1 to I_2 , the input voltage is given as:-

$$V_{in} = L\frac{I_2 - I_1}{T_1} = L\frac{\Delta I}{T_1} \tag{3.10}$$

The current across the inductor decreases linearly in time duration T2 from I_2 to I_1 and is given as:-

$$V_{in} - V_o = -L\frac{\Delta I}{T_2} \tag{3.11}$$

Where, ΔI =peak-peak inductor ripple current

Thus, from equation (3.5) and (3.6), it is noted that

$$\Delta I = \frac{V_{in}T_1}{L} = \frac{(V_O - V_{in})T_2}{L} \tag{3.12}$$

Placing, $T_1 = DT$, $T_2 = (1 - D)T$, we get the output average voltage as :-

$$V_O = V_{in}\frac{T}{T_2} = \frac{V_{in}}{1-D} \tag{3.13}$$

3.3 Buck-Boost Converter

The buck-boost converter is obtained by the cascade combination of buck converter and boost converter. The operation of converter is carried out in two modes:

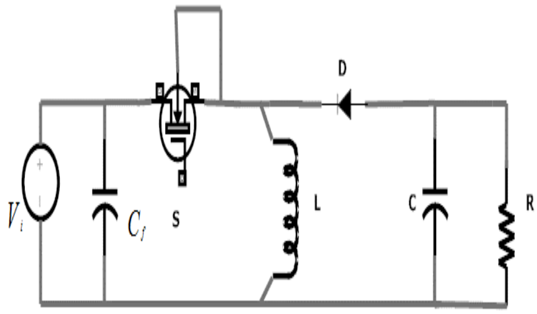

Figure 21- Buck Boost Converter

In mode 1, when switch S1 is switched on and diode D is reverse biased the input current flows through inductor L and switch S1.In mode 2, when switch S1 is switched off and the inductor current flows through inductor L, capacitor C, load and diode D, the inductor energy is transferred to the load and the inductor current (iL) decreases till next cycle.

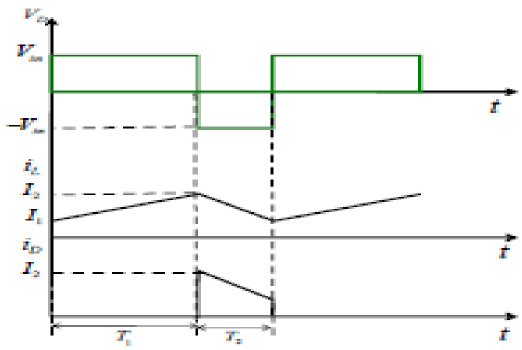

Figure 22-Buck Boost Converter- voltage and current waveform

V_d= diode voltage

i_d =diode current

i_L = inductor current

The inductor current (i_L) is assumed to increase linearly from I_1 to I_2 considering the frequency of switch to be very high.

In mode 1, the input voltage is given by:-

$$V_{in} = L\frac{I_2 - I_1}{T_1} = L\frac{\Delta I}{T_1} \tag{3.14}$$

In mode 2, the current across inductor is assumed to fall linearly in time duration $\boldsymbol{T_2}$ from $\boldsymbol{I_2}$ to $\boldsymbol{I_1}$ and output voltage is given by

$$V_o = -L\frac{I_2 - I_1}{T_2} = -L\frac{\Delta I}{T_2} \tag{3.15}$$

The inductor peak-peak ripple current is given by:-

$$\Delta \boldsymbol{I} = \frac{\boldsymbol{V_{in}T_1}}{\boldsymbol{L}} = -\frac{\boldsymbol{V_O T_2}}{\boldsymbol{L}} \tag{3.16}$$

Where, T_1=DT

T_2= (1-D) T

This gives output voltage as:-

$$V_O = -\frac{V_{in}.D}{1-D} \tag{3.17}$$

and, peak-peak current ripple ($\Delta \boldsymbol{I}$) is given as:-

$$\Delta I = \frac{T.V_{in}.V_O}{L(V_O - V_{in})} = \frac{D.T.V_{in}}{L} = \frac{D.V_{in}}{f.L} \tag{3.18}$$

CHAPTER 4

MPPT Algorithms

CHAPTER-4

Maximum Power Point Tracking Algorithms

If the dc-dc converter is directly connected to the photovoltaic module, then the voltage profile obtained is flat, thus the system does not give maximum power with response to change in irradiation and other atmospheric conditions. Thus, the converter should adjust the input parameters to converter (that is, current and voltage) from the incoming photovoltaic module in response with the change of atmospheric conditions and system fluctuations. Here, in fig (23), the “dynamic optimizer” is the DC-DC converter having the controlling parameter as duty cycle d. The MPPT controller adjusts the duty cycle d in accordance with the system fluctuations to extract the maximum power from PV module.

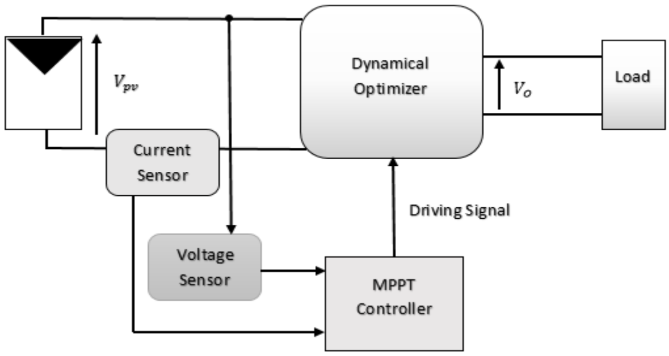

Figure 23-MPPT Circuit

Various MPPT control methods which are available are:-

1. Perturb & Observe (P&O)
2. Incremental Conductance (INC)
3. Voltage based peak power tracking method.
4. Current based peak power tracking method.

Among these, the Perturb & Observe (P&O) and the Incremental Conductance (INC) MPPT methods are most used. In this chapter, we focus upon Perturb & Observe method, INC method and direct duty ratio control. But, in this thesis, we are using P &O method because of its simplicity and changes to voltage and current can be done to extract maximum power.

4.1 Incremental Conductance Method

Incremental conductance method is based on slope of di/dv (that is, derivative of the current w.r.t voltage) so as to reach the maximum power point. Maximum point is obtained when di/dv is equal to value –i/v. Thus, by varying the voltage and changing it towards the largest value or lowest value alters the value of power. The voltage should continue in same direction if power is increasing and should reverse the direction, if power is decreasing.

It is based on the derivative of power vs voltage whose value is nil at MPP, but have positive value at the left of MPP and negative value at the right of MPP.

INC condition for maximum power point is given as:-

$$dP/dV = 0, \text{ at the MPP point} \tag{4.1}$$

$$dP/dV > 0, \text{ at the left of MPP point}$$

$$dP/dV < 0, \text{ at the right of MPP point}$$

The derivative of power vs voltage is given as:-

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} = I + V\frac{\Delta I}{\Delta V} \tag{4.2}$$

Thus the value of equation (4.1) for MPP is found to be:

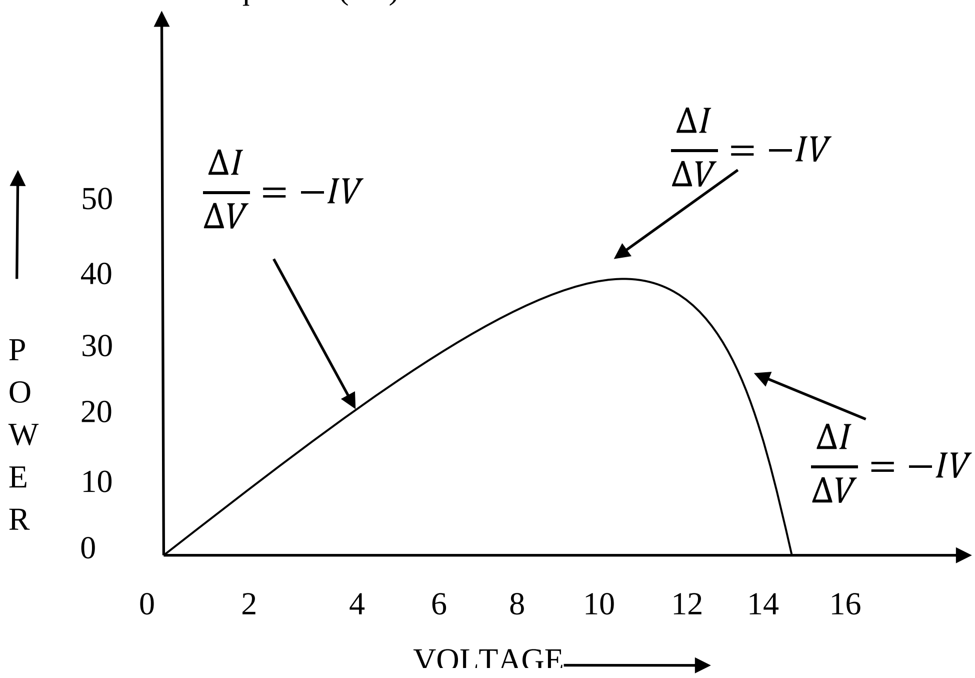

Figure 24-Graph Power versus Voltage for IC

$\frac{\Delta I}{\Delta V} = -IV$, at MPP
$\frac{\Delta I}{\Delta V} > -IV$, left side of MPP
$\frac{\Delta I}{\Delta V} < -IV$, right side of MPP

Basic Flowchart for INC MPPT Algorithm

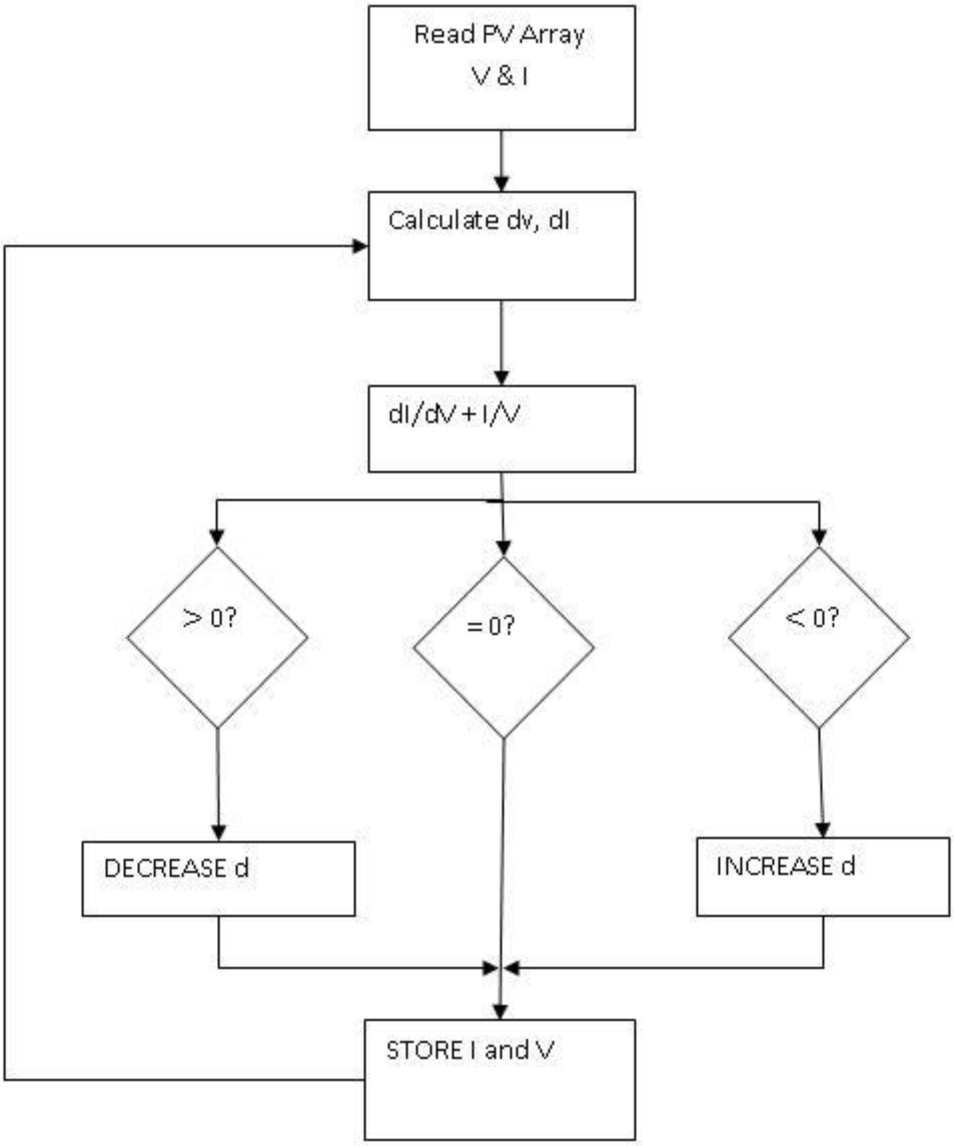

Figure 25-Basic Flowchart for INC MPPT Algorithm

4.2 Perturb & Observe (P&O) Method

The P & O algorithm is operated by shifting the operating point by increasing or decreasing (that is, periodically perturbing) the terminal voltage or current and thus comparing with the output power of the previous perturbation cycle. Voltage or current increases in the same direction if the power increases. If power decreases then the voltage or current varies in the reverse direction. Here, the operating point is shifted towards MPP by changing the voltage and current. In P&O the PV operating point keeps on perturbing (increase or decrease) by changing the PV terminal voltage. The controller calculates the PV source power before and after each perturbation, and if the PV power is increased above the previous value after each change, then the operating point is shifted towards the MPP. However, the sign of operating point remains same because of subsequent perturbation applied to the voltage. The operating point is considered to be shifted far from MPP if the PV power is decreased below the previous value. There are two methods used in P & O algorithm so as to control and change the voltage of dc-dc converter. The first method is to change the duty cycle of the converter directly and the second method is to change or perturb the reference voltage of error amplifier so as to control the duty cycle of the signal.

The P & O methods that are used to control the system are as follows:

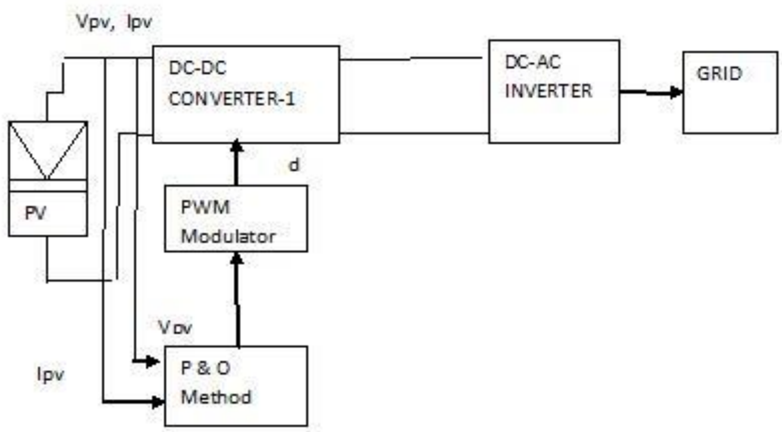

Figure 26-P&O method

As shown in the fig (26), the first method does not have any feedback loop and the second method consists of a voltage feedback loop after each perturbation.

The algorithm to describe P & O method is given as:

$$x_{\left((k+1)T_p\right)} = x_{(kT_p)} \pm x = x_{(kT_p)} + \left(x_{(kT_p)} - x_{\left((k-1)T_p\right)}\right).sign(P_{(KT_p)} - P_{((K-1)T_p)}) \tag{4.3}$$

Basic Flowchart for P &O MPPT Algorithm

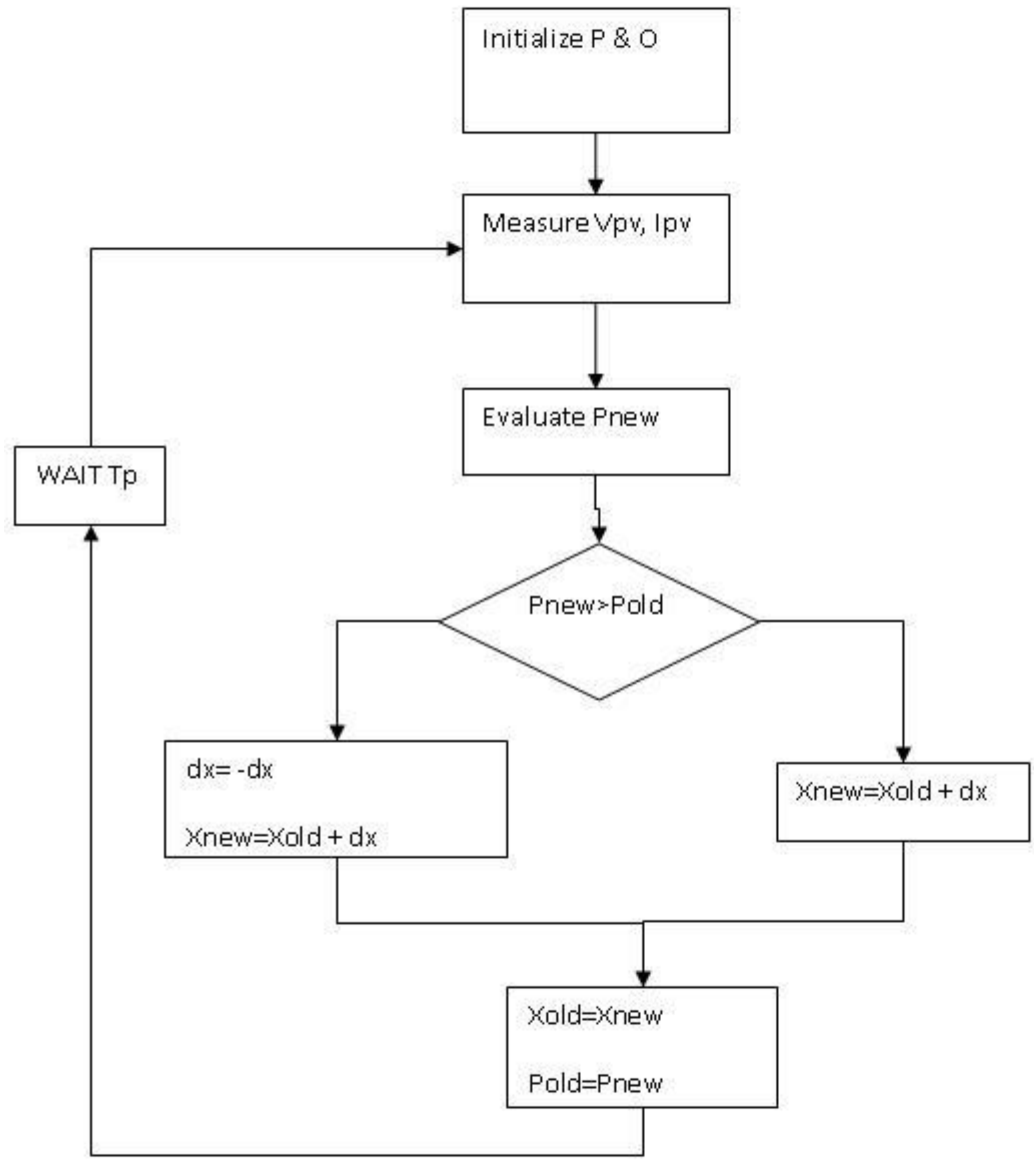

Figure 27-Flowchart for P &O MPPT Algorithm

The demerit in P & O MPPT method is that the system oscillates about the Maximum Power Point once the operating point reaches towards it and the system loses its energy. However, the disturbance is minimized by small step size but it increases the tracking time. Similarly, large step size causes increases the disturbance but decreases the tracking time. Thus, it is noted that a wrong selection of the frequency and amplitude can lead to unreliability in case of perturb and observe (P&O) method.

4.2.1 Improvement of the P&O algorithm

Thus, P&O MPPT algorithm is most widely used MPPT method because of its simplified control design and the simplicity in its application. But, in this algorithm fixed amplitude and frequency parameters $[\Delta x, Tp]$ must be optimized so that the controller values are selected to match the system energy losses due to large changes around the MPP because of steady state and the MPPT rate due to extreme atmospheric conditions and fluctuations. The two methods are adaptive size and parabolic approximation method that are used to improve and optimize the performance of P&O MPPT algorithm.

4.3 Conclusion

Thus, in this chapter we have discussed various MPPT algorithm and the steps to maximize the efficiency of system. We have studied the improved variety of P & O method which is called Incremental Conductance (INC) method. The maximum power is tracked better through an Incremental Conductance (INC) method than using P & O method. But, the usage of P&O algorithm is high because of the simplified control implementation and simplicity in design implementation. However, as the operating point moves towards the MPP, the system loses its power which is because of the oscillating nature around the MPP. However, the P&O algorithm is corrected by using several methods.

CHAPTER 5

DMPPT and Cross-coupling effects

CHAPTER 5

5.1 Distributed Maximum Power Point Tracking

The major disadvantage of photovoltaic (PV) systems is the effect of module mismatching and of partial shading on the photo-voltaic field. So, to increase the system efficiency and reliability of such systems, distributed maximum power point tracking (DMPPT) is used which is a very promising technique where each dc-dc converter is dedicated to each module and MPPT operation is performed. Modelling and designing a PV system with DMPPT is remarkably more complex than implementing a standard MPPT technique. The photo-voltaic system is made of several series connected photo-voltaic arrays (strings) connected in parallel. Usually, cells in a PV field are assumed to be of the same type, or even equal, but in practical there is mismatching due to manufacturing tolerances and aging-related parametric drift. The current is different because of different orientation of photo-voltaic module and photo-voltaic field and because of shadowing effects; there is mismatch in photo-voltaic field resulting in very high different currents in some photovoltaic modules. The bypass diodes are connected in anti-parallel to series connected photo-voltaic cells so that one shadowed PV cell does not prevent the others resulting in narrowing of current path in a photo-voltaic string, thus downgrading the other PV ones in the series and thus, reducing the photovoltaic power production of the whole string. There is increase in system power and efficiency of photovoltaic field resulting in power versus voltage operating point P-V characteristic multimodal. There is a consistent fall of overall photo-voltaic system efficiency because of fault in maximum power tracking (MPPT) technique leading to several operating points in PV operation characteristic due to mismatching conditions. The detection of the absolute maximum power point (MPP) of the PV field is complicated because of presence of more than one operating peak in such PV characteristic. In DMPPT, a system composed of a PV module with a dedicated dc–dc converter will be referred to as self-controlled PV module (SCPVM). Self-controlled PV module (SCPVM) functions as distributed MPPT where each photovoltaic module has dedicated dc-dc converter and MPPT operation is performed. For MPPT application, several dc–dc converter topologies are focussed upon, and among them are buck, boost, buck–boost, where the converters are cascaded so as to increase the system efficiency and performance. Thus, an self-controlled PV module can be considered as an intelligent PV module.

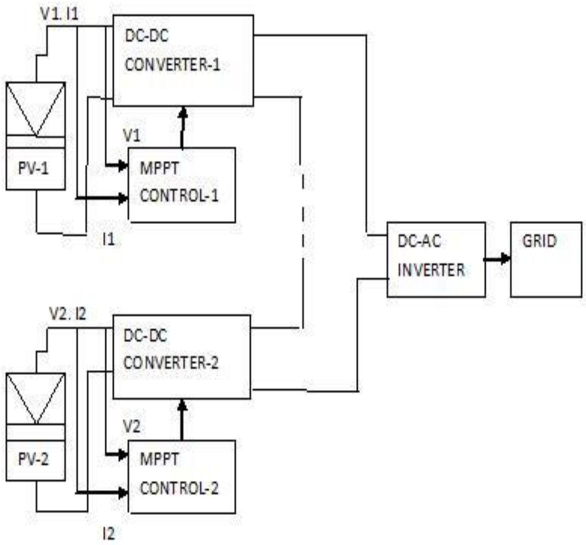

Figure 28-Distributed MPPT

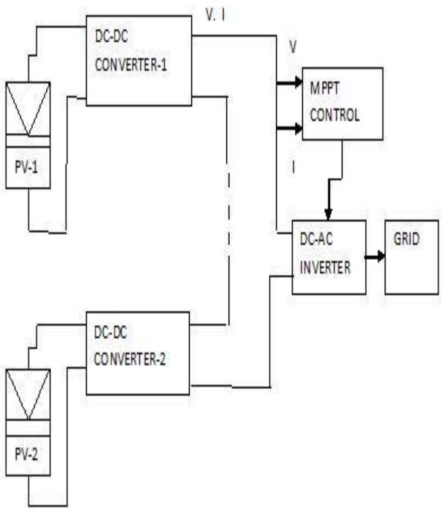

Figure 29-Standard MPPT

The input voltage range of Grid-connected inverters usually varies from 180 to 500 V. Therefore, a number of photo-voltaic modules are usually connected in series so as to supply the inverter with an input voltage within its operating range, and identical PV strings are then connected in parallel to achieve the desired output power**.** The maximum power point of DMPPT can be found out by various MPPT techniques. Among them, perturb and observe (P&O) technique is considered in this paper because of its simple and high performance and cost-effective photo-voltaic implementation of the grid**.** As shown in Fig.28, every disturbance present on the characteristic plot of output voltage is directly propagated on to the photo-voltaic module output voltage by the inverter or by other photo-voltaic modules. This may result in causing instability in the system and degrading the dynamic performance of the system. The power available gives the sum of maximum powers of the different modules under the mismatching conditions while in case of standard MPPT technique as shown in fig-29, the power that is extractable by a photo-voltaic field consists of a unique string of *N* PV modules, consisting of bypass diodes, and assuming that MPPT technique is able to locate the absolute maximum power among the several relative maximum power points that may appear due to mismatching conditions. The efficiency due to DMPPT is found out to be always more than the efficiency which may be due to standard MPPT.

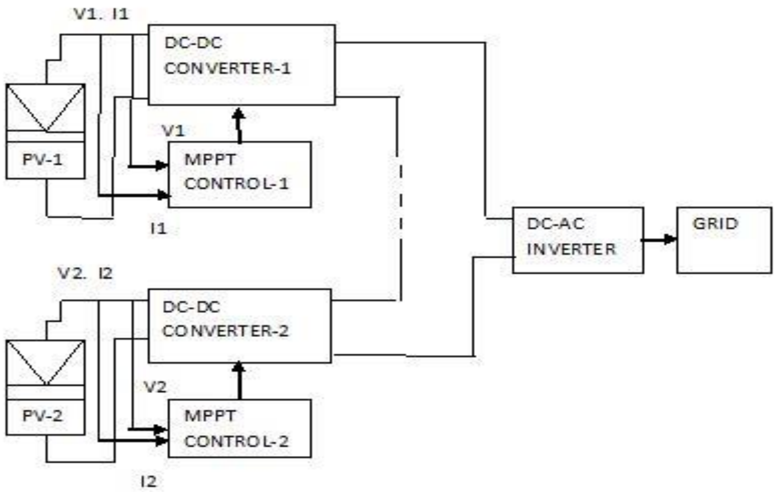

Figure 30-DMPPT connected to grid

In grid connected DMPPT, DMPPT converters shows first part of the PV system where the power which is produced from PV modules is transferred to the grid with the help of DC-AC inverter. The system consists of PV modules, DC-DC converter and DC-AC inverter. Figs. 31 and 32, shows the DMPPT series and the DMPPT parallel topologies. In series configuration, the outputs of each interfacing dc-dc converters are connected in series cascade. This results in increase of system voltage. However in parallel configuration, the output terminals of interfacing dc-dc converters are connected in parallel cascade thus resulting in constant voltage and increase of current. So to track the MPP, the P&O algorithm is used which gradually increases the photo-voltaic panel voltage and continue to increase till there is a limitation of duty-cycle. This condition defines the area of concern when the operating point of PV system in the feasibility map hits the boundary of a feasible region. The trajectories of PV system are not fully defined in the feasibility regions because the feasibility regions are because of steady-state operation, whereas trajectories are the instantaneous operating behaviour because of transient start-up of photo-voltaic system. The effect on PV trajectory is because of the mixed effects of the limitation of duty-cycle and MPPT effects.

5.2 Cross-Coupling Effects

Cross-coupling effects are the undesirable disturbance properties of interconnected cascaded converters which results in unsettling influences on the behaviour of the other converters because of disturbance in one of the converter. The effect of cross-coupling is because of poor MPPT execution and when there is a sudden step change in the irradiation level the output voltage is varied quickly of the corresponding DC-DC converter which results in power adjustment. The alternate dc-dc converters get influenced because of this unsettling behaviour thus resulting in individual controllers to change their duty cycle according to system performance. The performances of dc-dc converter gets deteriorated when there is sudden changes in irradiation occurs, thus requiring new framework to achieve the new system consistent state conditions. It was seen that in series DMPPT configuration because of sudden change in illumination, disturbances takes place which is called as cross-coupling effects which affects the operation of other DC-DC converters whereas in parallel configuration, the cross-coupling effects are not present or minimised.

5.3 Cross-coupling effects in series DMPPT

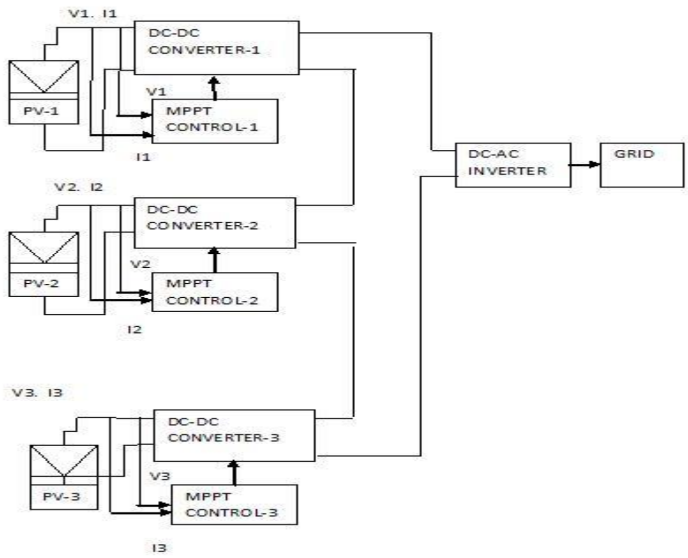

Figure 31-Series DMPPT model

Since the converters are connected in series, the individual voltage adds up to give the system output voltage. The current must be same for each converter as they are connected in series. However because of partial shading, the current in each converter are different resulting in uneven power. So, DMPPT technique is used to extract maximum power under such conditions. The output voltage for a series connected DMPPT dc-dc converter is given by:

$$V_i = \frac{P_{PV,i}}{\in P_{PV}} * V_{Link} \tag{5.1}$$

Where V_i= converter output voltage,

V_{Link}= dc link output voltage

$P_{PV,i}$=PV module power which is connected to the individual converter i,

$\in P_{PV}$ =total power generated by PV modules

This restrain in operating point for e.g.-current in case of series-connected dc-dc converters thus resulting in fall of converter efficiency. In series DMPPT, there is only one fixed input parameter that is input current. It is noted that, if the source behaves as current source, then the cross-coupling effects are more whereas if each converter behave as voltage source with small output impedance, the cross-coupling effects will be less.

5.4 Cross-coupling effects in Parallel DMPPT

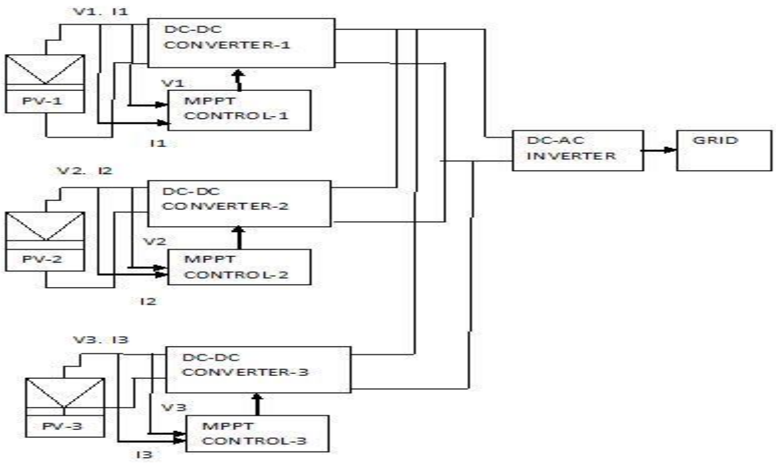

Figure 32-Parallel DMPPT connection

In a parallel DMPPT configuration (Fig. 32), each output converter terminal voltage is constant because of the constant dc bus voltage. The dc bus voltage is maintained constant by a grid inverter which maintains its own dc input voltage such that dc-dc converters behave as current sources. Because of current source nature of the system, the parallel connection does not have any restrictions of operating point as it is in series connection. In parallel DMPPT, there are two fixed control input parameters-one is input current and other is output voltage. Whereas in series DMPPT, there is only one fixed input parameter that is input current. In parallel DMPPT, the converter input voltage is product of modulated duty cycle and output voltage. The output voltage in parallel DMPPT is not disturbed by the neighbouring dc-dc converter. In parallel DMPPT, the system does not introduce the cross-coupling effects so also the non-ideal sources. In series DMPPT, the cross-coupling effects are present because of system configuration.

5.5 SIMULATION

A -Solar Irradiation to PV modules

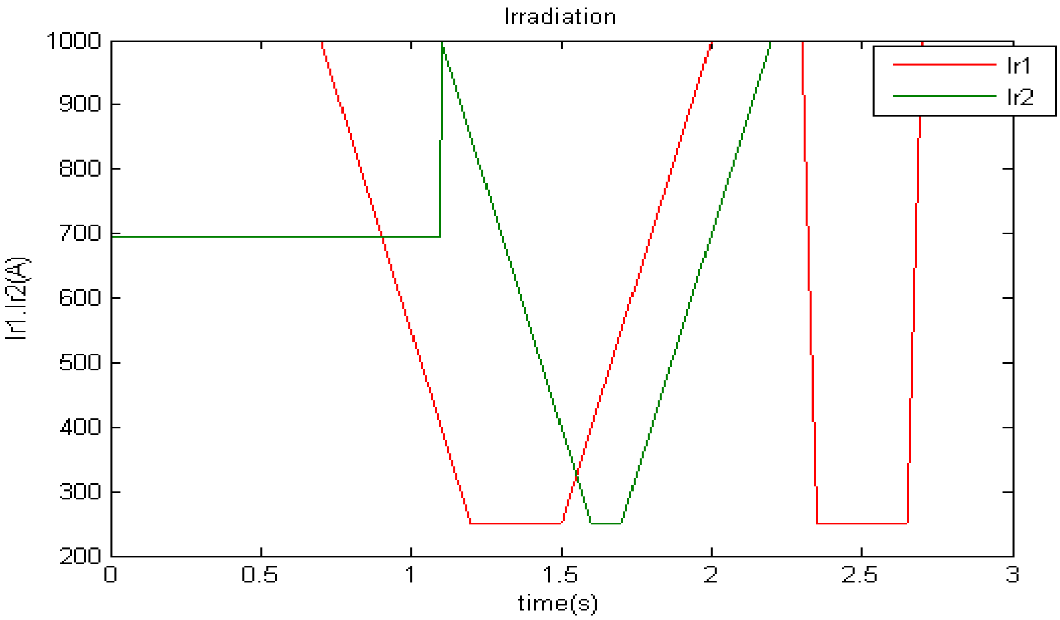

Figure 33-Solar Irradiation to PV modules

<u>Parameters for Perturb and Observe Algorithm-(for DC-DC converters)</u>

L	150e-6 H
C	220e-6 F
f	20kHz /Time=5e-6 sec
Initial value for D output (Dinit)	0.5
Dmin to Dmax	0.42-0.52
(ΔD)	3e^-4

B. PARALLEL BOOST DMPPT MODEL

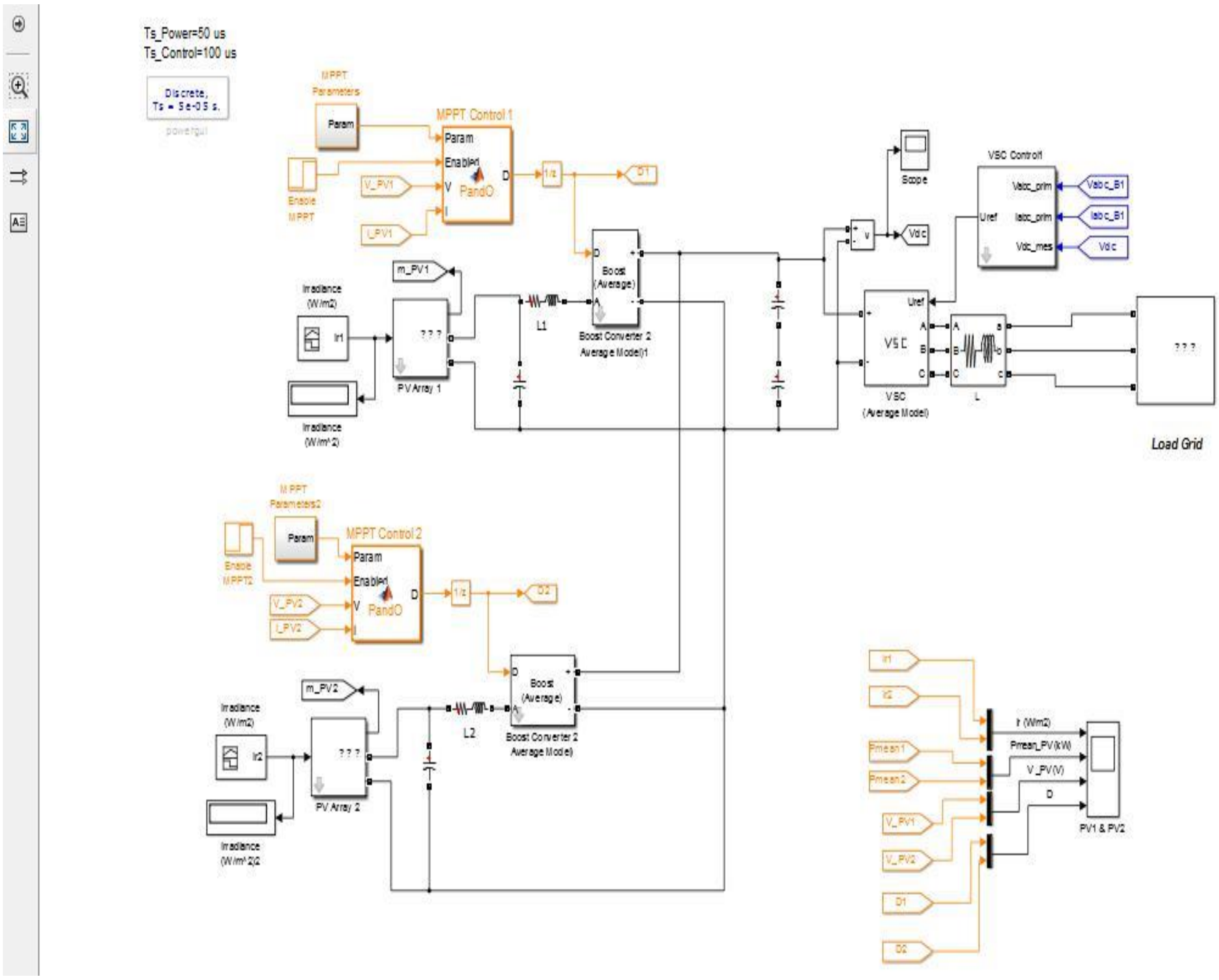

Figure 34-PARALLEL BOOST DMPPT MODEL

C. SERIES BOOST DMPPT MODEL

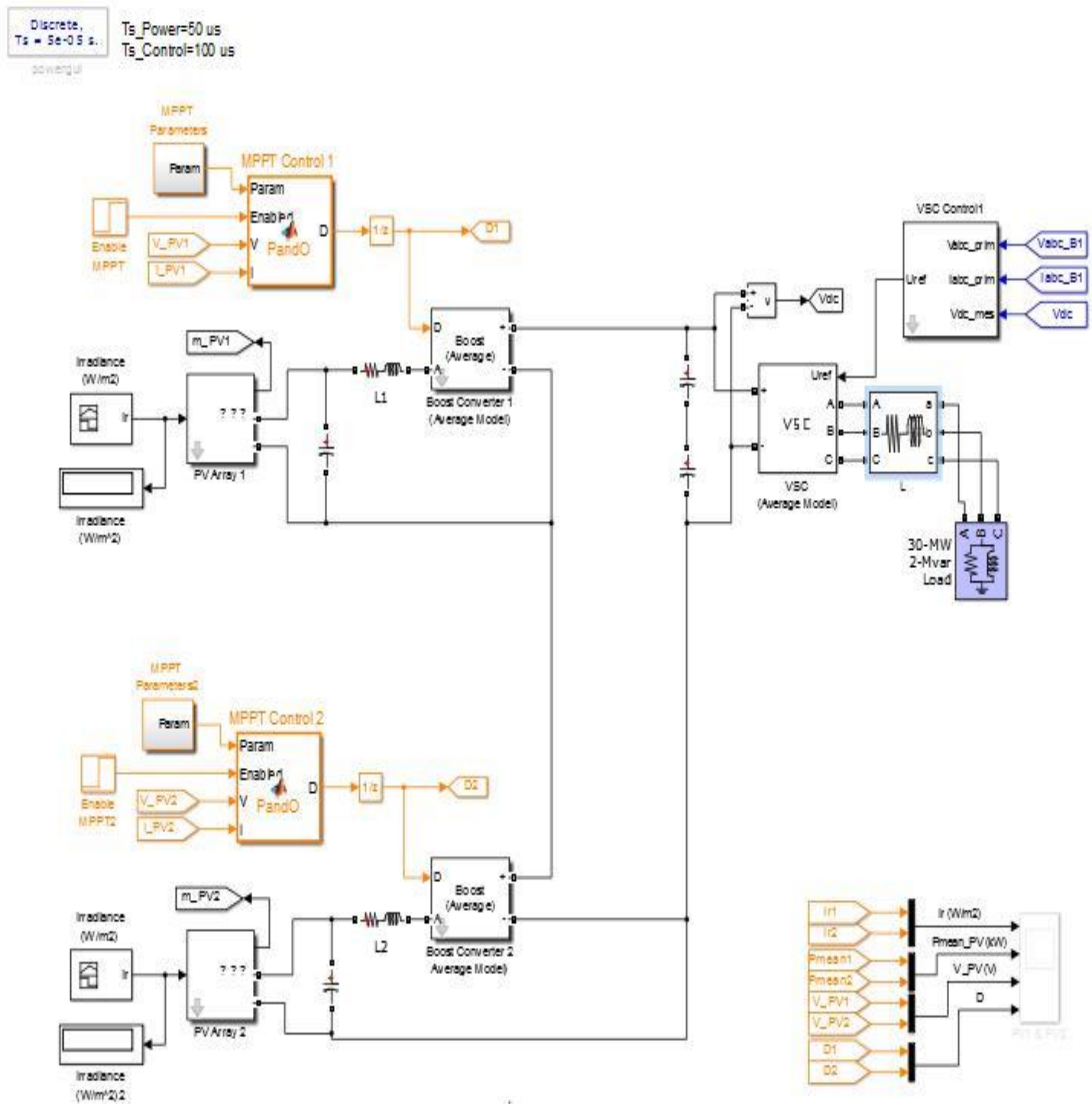

Figure 35-SERIES BOOST DMPPT MODEL

D. PARALLEL BUCK DMPPT MODEL

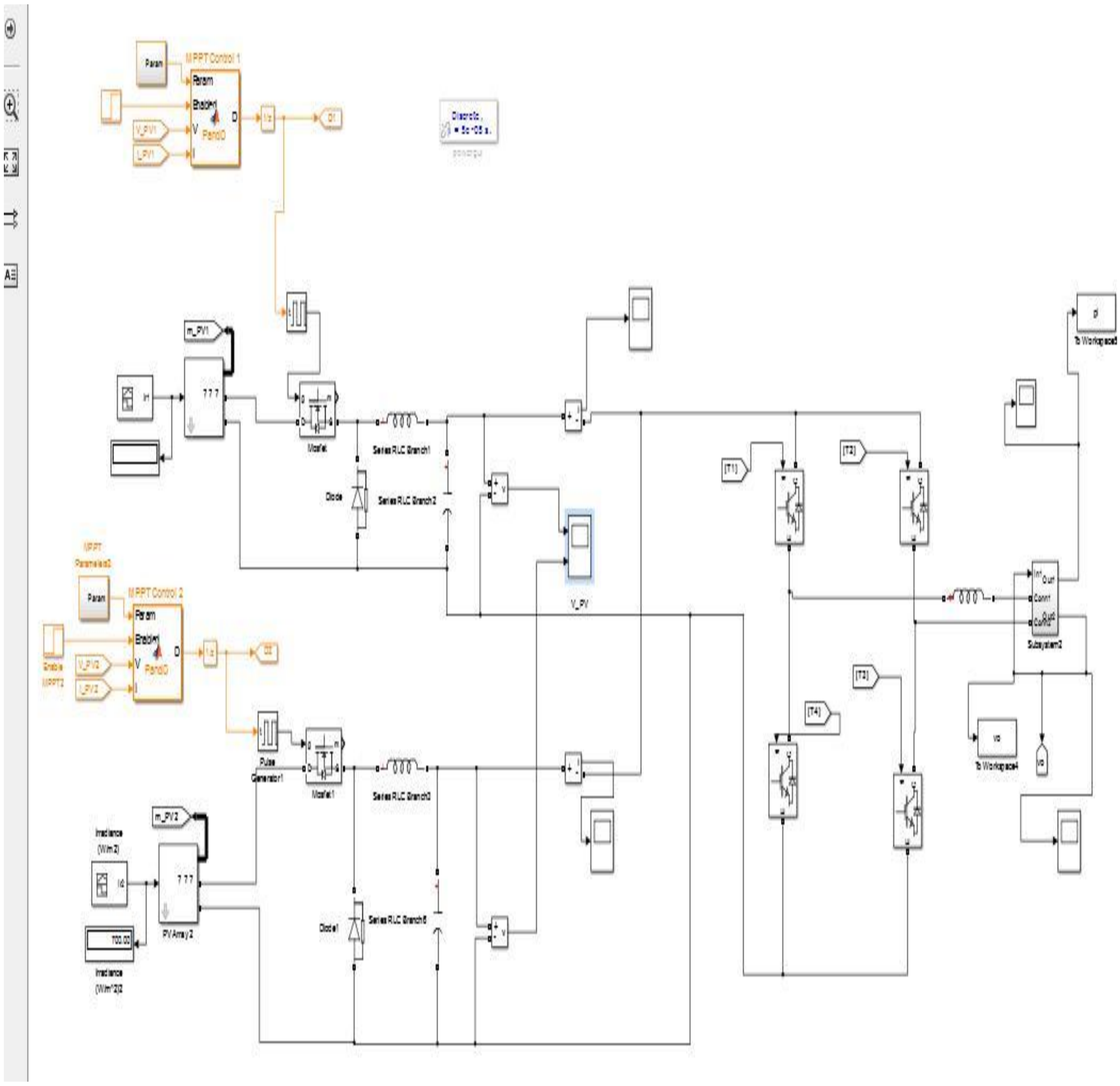

Figure 36-PARALLEL BUCK DMPPT MODEL

E. SERIES BUCK DMPPT MODEL

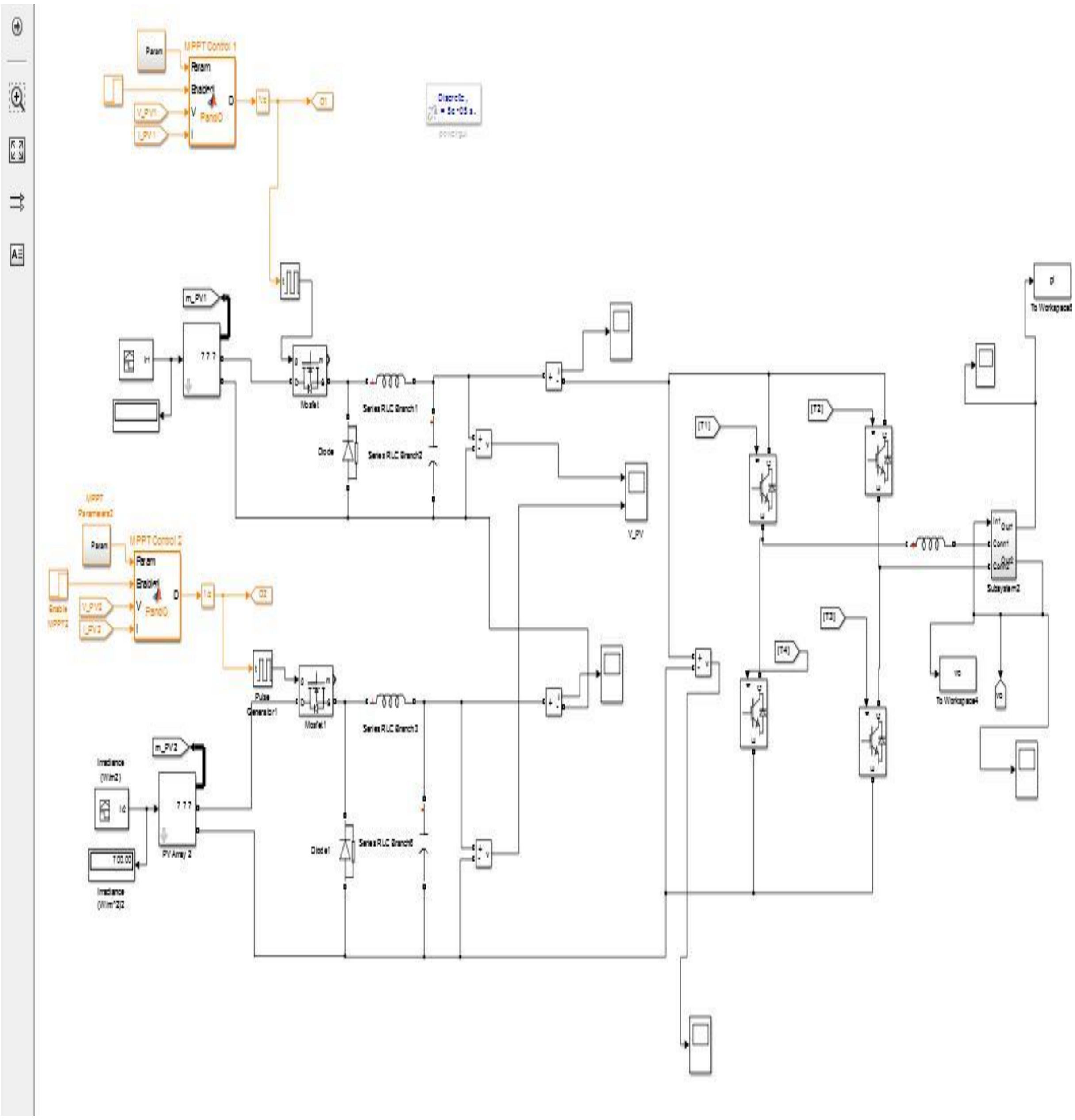

Figure 37 -SERIES BUCK DMPPT MODEL

5.6 RESULTS

The topologies of distributed MPPT system was simulated in MATLAB and the comparison results are noted below.

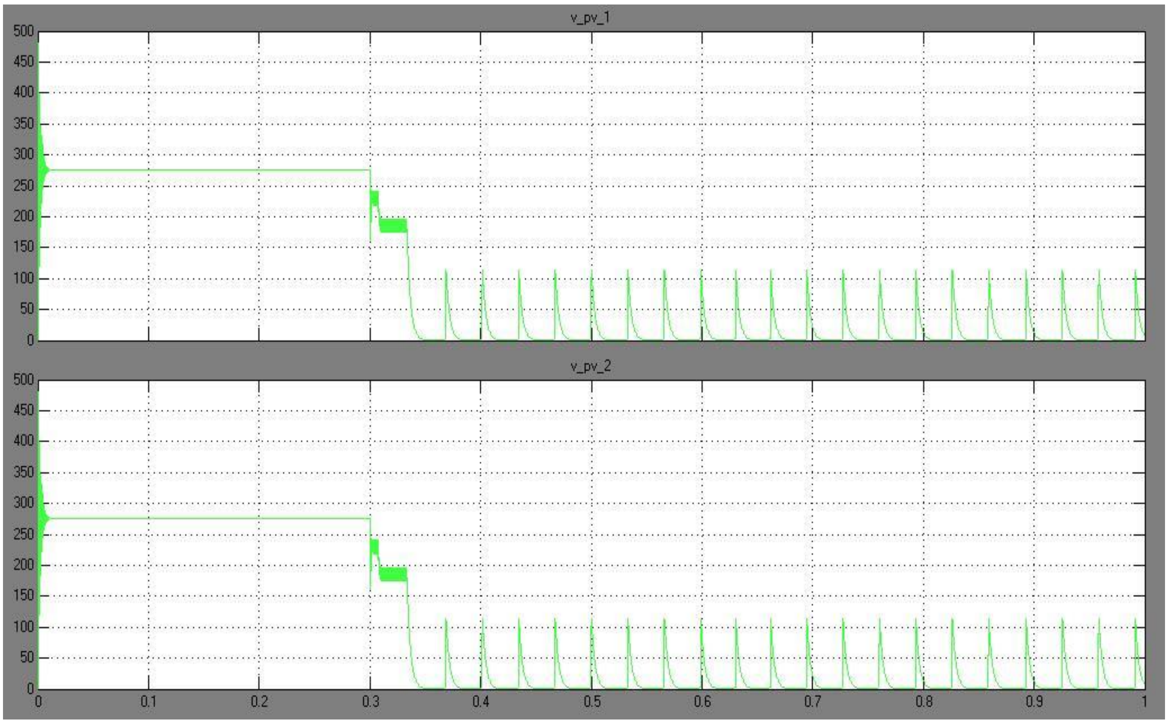

Figure 38- Cascaded Parallel Buck converter-P & O METHOD

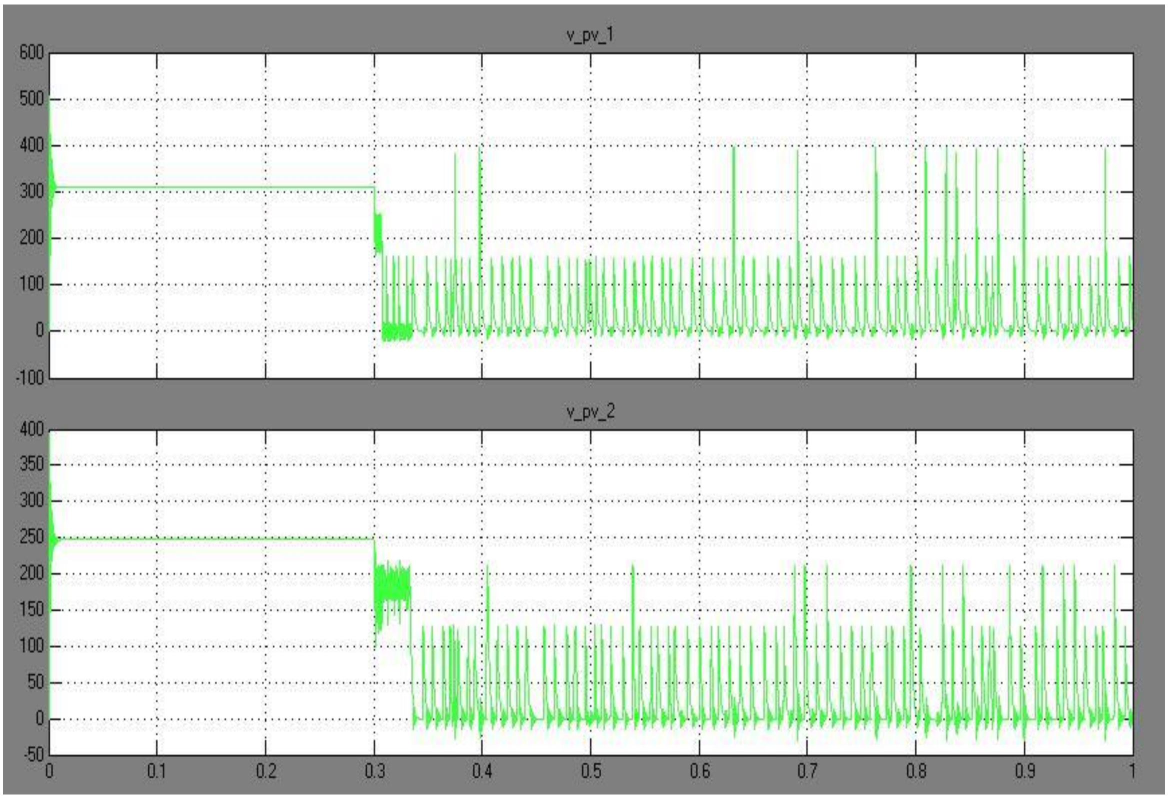

Figure 39- Cascaded Series Buck converter-P & O METHOD

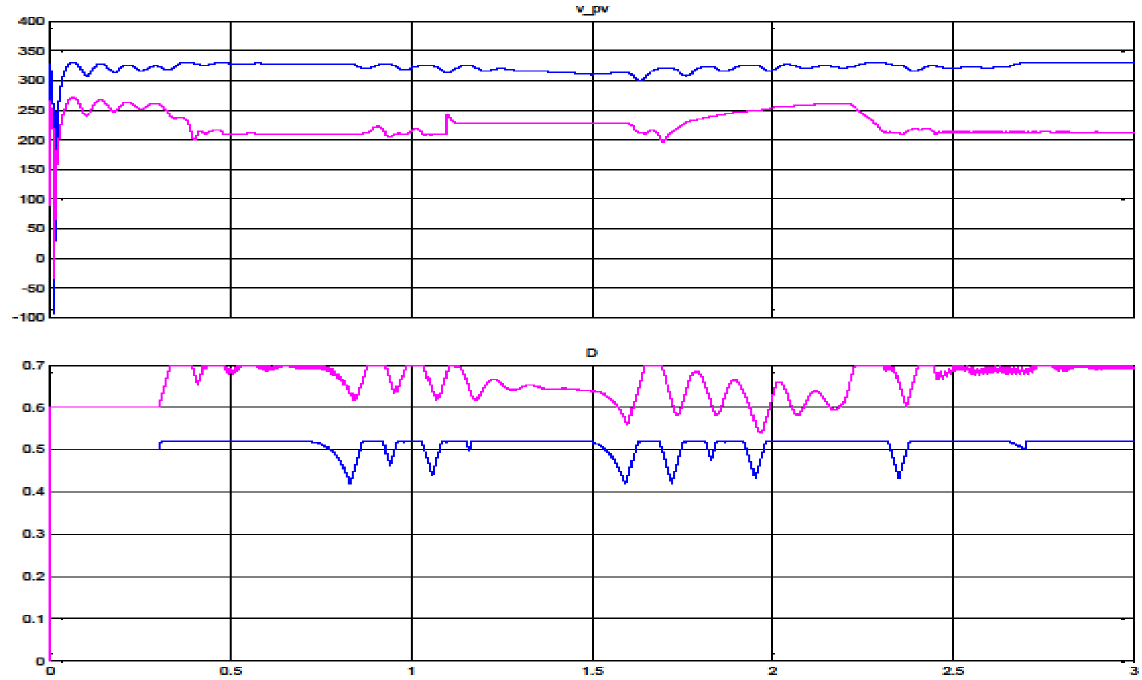

Figure 40-Cascaded parallel Boost converter-P & O METHOD

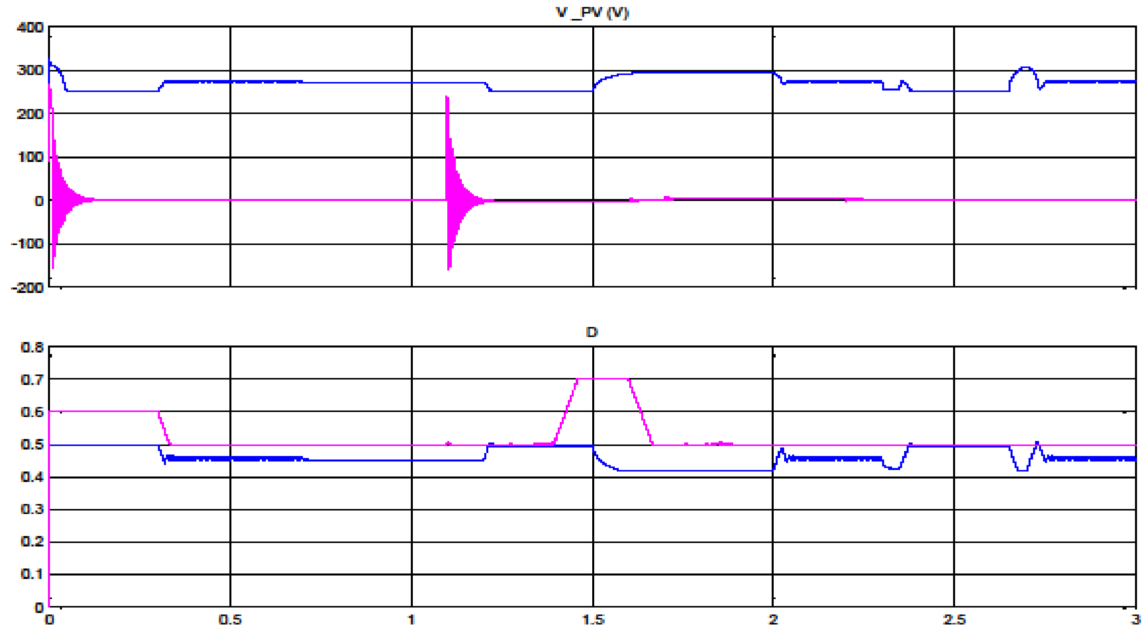

Figure 41- Cascaded Series Boost converter-P & O METHOD

I. CONCLUSION

The cross-coupling effects are thus found to be present in series distributed MPPT systems and this existence of undesirable disturbance properties of interconnected cascaded converters found are called cross-coupling effect. Thus, we have covered various aspects starting with PV modelling in chapter-2 and then followed by modelling various dc-dc converter topologies In chapter-3. We continue to cover various MPPT algorithms available to extract maximum power in chapter-4 followed by in chapter-5 where we discussed extracting maximum PV module power using DMPPT algorithms under atmospheric conditions for the improvement in system efficiency and studying the cross-coupling effects. It is noted that the output voltage in parallel DMPPT is not disturbed by the neighbouring dc-dc converter. In parallel DMPPT, the system does not introduce the cross-coupling effects so also the non-ideal sources. But, in series DMPPT, the cross-coupling effects are present because of system configuration. In parallel DMPPT, there are two fixed control input parameters-one is input current and other is output voltage. The parallel connection does not have any restrictions on the operating point as it is in series connection .Whereas in series DMPPT; there is only one fixed input parameter that is input current. The dc bus voltage is maintained constant by a grid inverter which maintains its own dc input voltage such that dc-dc converters behave as current sources. It is noted that in series DMPPT, if the source behaves as current source, then the cross-coupling effects are more whereas if each converter behave as voltage source with small output impedance, the cross-coupling effects will be less.

II. FUTURE WORK

The future project work involves finding solution to minimize or reduce the effect of cross-coupling thus making each individual converter module not dependent on one another and thus suppressing the cross-coupling effects.

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